BRICK AND TILE ENGINEERING

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HANDBOOK OF DESIGN

By

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PREFACE

THIS VOLUME is a revised edition of those sections of Brick Engineering and Tile Engineering published by the Structural Clay Products Institute in 1939 and 1946, respectively, which deal with unreinforced masonry. It does not include reinforced brick masonry and structural tile floors, both of which are covered in other publications of the Institute.

The purpose of this book is to include in one volume the best available engineering data on brick and tile construction. In the main, the subjects covered relate to the engineering aspects of design, rather than the architectural. Exceptions are Chapter 2 on Modular Masonry and Chapter 12 on Bond.

The author acknowledges the substantial contributions to this book of Leslie J. Reardon, Professor of Applied Mechanics, Case School of Technology, and Edwin F. Wanner, Chief Engineer, National Fireproofing Corporation, the co-authors of Brick Engineering and Tile Engineering, respectively; and the valued criticisms and suggestions of D. E. Parsons, Chief of the Building Technology Division, National Bureau of Standards; J. W. McBurney, Senior Technologist, National Bureau of Standards; and Leonard G. Haeger, Assistant Director, Program Coordination, Division of Housing Research, Housing and Home Finance Agency. Acknowledgment is also made of the assistance given by the staff of SCPI, particularly Sarah A. Hardy, secretary to the Director of Engineering and Technology.

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CHAPTER 1

ORIGIN AND MANUFACTURE

101. HISTORY AND DESCRIPTION

Structural products are defined in the American Standard Basis for the Coordination of Dimensions of Building Materials and Equipment A62.1-1945 as "building material units which, when assembled in a structure, support their own weight. They may be load-bearing (designed to support loads in addition to their own weight) or non-load-bearing (designed to resist no loads other than their own weight). Materials, such as wall finishes, windows, doors, and equipment, that are attached to and supported by structural materials are not included as structural products."

Structural clay products are manufactured from clay, shale, fire clay or mixtures of these materials and hardened by heat. The so-called heavy clay products industry of modern times consists of the manufacturers of brick, structural clay tile, terra cotta, tile and drain pipe. All of these products are of ancient origin, with the exception of structural clay tile which was first produced in the United States about 1875.

Brick, structural clay tile, and, to a limited extent, terra cotta are structural products, while tile is primarily a finish material. However, since all stem from the same source, the history of the entire group must be considered in tracing the origin of any one member.

A. Hamilton Chute writes in his book, "Marketing Burned Clay Products," published June 1939:

"The potter's art dates back nearly to the close of the Old Stone Age, and the Neolithic stage of culture probably added, to other improvements in that handicraft, the use of a crude form of potter's wheel. Archeological literature describes fragments of decorative pottery excavated during the past century which are ascribed to periods as early as 5000 or even 8000 B. C. Egyptian borings and excavations have yielded bricks from tombs of the Memphite period (5000-3000 B. C.), and terra cotta vases intended to contain provisions for the deceased, which vases may have passed in commerce from the potters to mourning families. Pictures on tomb walls depicted the life of the potters around the Theban period (3000-1700 B. C.), when glazes and a more perfect earthenware supposedly were developed. Temple decorations of a rare perfection survived from a temple of Rameses III in a later period. Crude bricks have been found in the ruins of early Chaldean and Assyrian cities, and those from the ruins of Nineveh and Babylon sometimes bore colored glazes. Tombs have been found that were made of a single piece of pottery ware or formed of two pieces cemented together.

"The Chinese record the manufacturing of pottery from about 2600 B. C., and their impermeable pottery (stoneware and china) is attributed to about 150-200 B. C. The Aztecs are believed to have manufactured terra cotta about 1000 B. C. The Persians made very fine monumental earthenware and later

developed vases and dishes and an enameling process. The Greeks contributed greatly to the artistic development of terra cotta pottery and the Romans made important advances in the use of burned-clay products in their engineering and construction."

BRICK, the oldest of the structural clay products group, and in fact the oldest manufactured building material, was probably one of the first products that man manufactured from clay. As indicated by Chute, the origin of brick may be attributed to the potter. However, after the organization of the brick mason's craft, which it is claimed occurred during the construction of King Solomon's temple, the masons often manufactured the brick which they used and thus contributed to the art of brick making as well as masonry construction.

Perhaps the earliest recorded reference to brick is in the Bible, Genesis II, where in 2247 B. C. it was written that the descendants of the sons of Noah said: "Go to. Let us make brick and burn them thoroughly."

For centuries, the term brick has been applied to a solid building unit of dry or burned clay of various sizes but never larger than one man could handle easily.

Many of these brick contained recessed panels or "frogs" in which the ancient clay workers frequently molded inscriptions relating to the structure in which the brick was to be used, its owner or the potter himself. Modern manufacturers have utilized this panel as a means of identifying their brick by inscribing in it the manufacturer's name or trademark.

With the invention of the extrusion or stiff-mud brick-making machine, some manufacturers produced brick containing holes or "cores" running parallel to either the length or height dimension of the unit. These cores were introduced as an aid to uniform drying of the clay and as a means of reducing the weight of the unit.

Brick is now defined as a small building unit, solid or cored not in excess of 25 per cent, commonly in the form of a rectangular prism, formed from inorganic, non-metallic substances and hardened in its finished shape by heat or chemical action. The term brick, when used without a qualifying adjective, is understood to mean such a unit or a collection of such units made from clay or shale hardened by heat.

TERRA COTTA or Architectural Terra Cotta, as it is now known, is described by Charles Thomas Davis in his book, "Manufacture of Bricks, Tiles and Terra Cotta," published in 1884, as follows:

"Terra cotta is but another name for architectural enrichments of brick-work of various designs and shapes. The term is of Italian derivation, and, literally translated, means cooked or baked clay. This term was more appropriate to the ancient terra cotta, which was usually less burned, not so homogeneous and coarser in texture than with us, but that is not a true description of the process as now employed in converting the artistically molded clay into finished terra cotta.

"Terra cotta was largely used for architectural decorations in Greece, Etruria, Pompeii, Rome, and Mediaeval Italy, and it was in the clay plains of North Italy that terra cotta was first predominantly employed over other materials in architectural construction and ornamentation, and the inspiration of modern designs in architectural terra cotta is largely drawn from these works, especially those structures erected from the middle of the thirteenth until the commencement of the sixteenth century."

As indicated by Davis, terra cotta is of ancient origin and like brick, the shapes or blocks were molded and carved or otherwise decorated by hand. Like brick also, terra cotta was produced even in the days of early Greece with ceramic glaze as well as natural finishes.

Following the development of the extrusion brick machine, architectural terra cotta shapes of the simplest designs were machine made.

The development, about 1883, of so-called terra cotta lumber resulted in a confusion of terminology and the application of the name terra cotta to products which have little or no resemblance to the original product or to its rightful successor, the present architectural terra cotta.

Terra cotta lumber, as produced by the New York Terra Cotta Company in 1884, is described by Davis in his book previously referred to as follows:

"The New York Terra Cotta Lumber Company has established large works at Perth Amboy for the manufacture of lumber by mixing resinous sawdust with the wet clay, which is left porous after the burning, by the sawdust being consumed.

"The material is thoroughly ground and mixed in a mill, carried to the upper portion of the building by an elevator bucket belt. There it is shovelled into a compressor, through which it passes to the floor below, and is forced through a die into any requisite shape, and remains in that portion of the building for a time, to stiffen. It is then carried to the ground floor and dried on a brick floor heated by flues running underneath it from a furnace.

"It now goes in the form of slabs to the ovens, where it is brought to a great heat, which burns out the sawdust.

"This occupies about forty-eight hours, and produces in that period about one hundred and eighty tons of fireproof lumber.

"It is next planed, tongued, grooved, or sawed into any desirable shape, the dust being carried off by a steam blower."

Heinrich Ries and Henry Leighton, in their book, "History of the Clay-working Industry in the United States," published in 1909, credited the discovery of terra cotta lumber to a man named Gilman of Eldora, Iowa. These authors report:

"* * * He was a clay manufacturer who in 1883 made the experiment of mixing prairie soil with clay and found that it burned to a light porous block. This was used for absorbing alcohol, which he subsequently fired and placed under a receptacle for heating coffee.

"The attention of a New York architect being accidentally drawn to this porous block, he exclaimed: 'This is what I have always been looking for, for fireproofing purposes.' Mr. Gilman sought to carry out the idea and hit upon the use of sawdust as a desirable substitute for prairie soil.

"Whether or not Mr. Gilman was the actual discoverer of the method of making this porous fireproofing, it is true that ever since the introduction of fireproofing in the New Jersey works, there has been a steady and increasingly large demand for these hollow blocks, whether filled with sawdust or not, and now New Jersey stands as the leading producer."

Hollow brick, used for partitions, floors and fireproofing iron or steel structural members, produced from clays to which high (30-50) percentages of sawdust had been added, were used extensively during the early part of the 20th century and since these products were produced from the same raw materials as terra cotta lumber, they were improperly referred to as terra cotta or porous terra cotta, a practice which still continues in some parts of the coun-

try. However, as previously indicated, the term terra cotta has for centuries been applied to decorative molded clay units whose properties are similar to brick. This material is now known as architectural terra cotta and it would appear that the term should be limited to this product alone.

TILE is the term applied to relatively thin (less thickness than brick) solid slabs of burned clay.

With the exception of the tile arches and domes, known in this country as Guastavino arches after the Spanish architect, R. Guastavino, who introduced them here in 1885, thin tile is not ordinarily used as a structural material in the sense that it supports its own weight when built into the structure. It is used extensively as a finish or surfacing for floors, walls and roofs, and consequently is closely related to the other clay building materials. In addition to its use in buildings, tile has throughout the centuries served many useful purposes, one of which is described by Chute as follows:

"* * * As an example of the service of the potter's art to history, scores of thousands of inscribed baked-clay tablets of Babylonia and Assyria, recording ordinary and extraordinary incidents of daily life 2500 to 5000 years ago, are included in the ceramic treasures of British and foreign national museums. Among these 'documents' are bills of sale and other market records."

Roofing tile have been found in ruins dating back as early as 1000 B. C. and floor and wall tile, with both natural and glazed finishes, were in use prior to the Christian era. The production of tile flourished during the middle ages and Davis writes:

"Glazed decorative tiles were much used in mediaeval times for paving sacred edifices; they are sometimes called Norman tiles by old writers, from the supposition that they originated in Normandy. There are some specimens of great age in northern France; although no tiles have as yet been discovered in England that coincide with the features of the Norman style of architectural decoration, the most ancient being apparently of the thirteenth century."

Modern tile production includes wall, floor, and roofing tile, or as they are sometimes called, tile shingles, and tile approximately 1 in. thick, 6 in. wide and from 12 to 24 in. in length, used for the construction of the Guastavino arches referred to previously. Wall tile, particularly, are available in a wide variety of glazed and natural finishes.

DRAIN TILE, while not a structural clay product, is now produced by the same machines used for the manufacture of brick and structural tile, and many manufacturers produce all three products.

Like the other clay products which can be produced by hand, the origin of drain tile dates back to antiquity. However, it is more closely associated with the potter's craft as we know it today than the other members of the group.

Drain pipes have been discovered in excavations dating back to over 4000 B. C. Early drain tile were molded in various shapes; many of the cylindrical shapes, forerunners of the present designs, being shaped on the potter's wheel.

Sewer pipe, a modern development of drain tile, are commonly manufactured with a bell on one end, burned to the point of vitrification of the clay and, as a rule, salt glazed. Drain tile are produced without the bell, burned to lower densities and usually are unglazed.

As previously indicated, drain tile may be produced by an extrusion machine similar to that used for the production of structural tile. Sewer

pipe are manufactured by a machine in which the clay column flows in a vertical direction.

STRUCTURAL CLAY TILE is a machine made product and was first produced in this country in New Jersey in 1875. Structural clay tile are characterized by the fact that they are hollow units with parallel cells (hollow spaces). The shape of the unit is controlled by the die through which the clay column is extruded and the ease with which different designs could be produced led to the development of a wide variety of sizes and patterns.

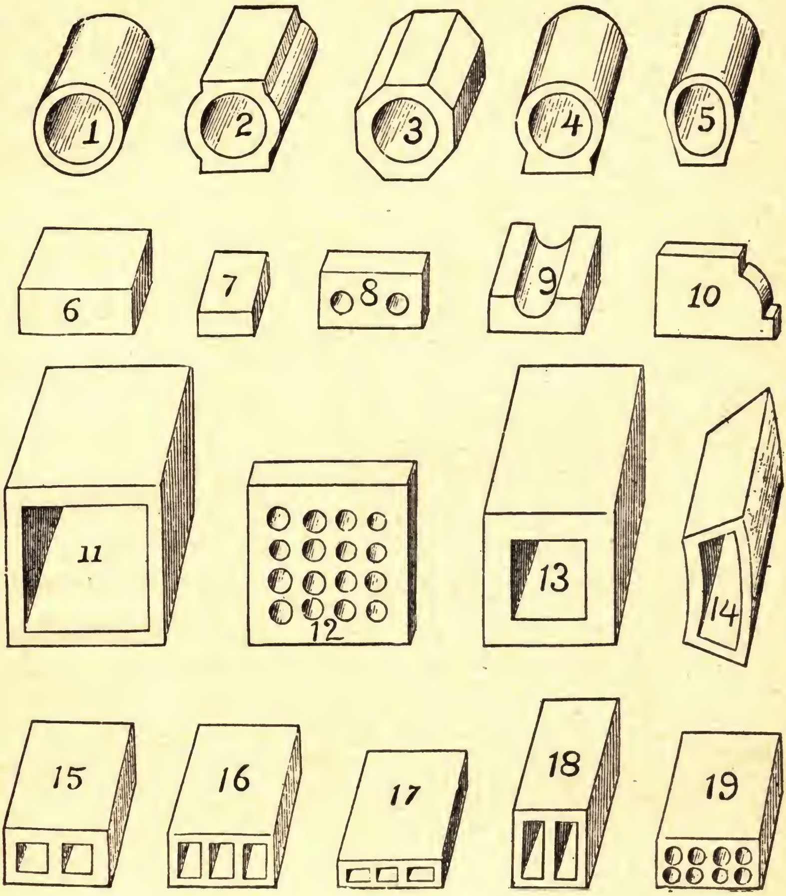


FIG. 1-1

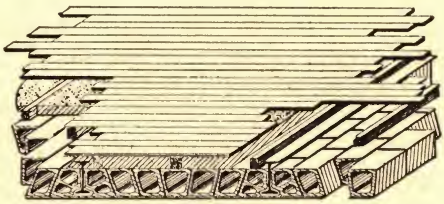
Original types of brick and tile

Fig. 1-1 and 1-2 are reproduced from Davis' book published in 1884 and show "different forms of bricks, tiles, and devices, which are made by some tempered-clay machines." While these units differ in detail from modern structural clay tile, many of the basic principles of present-day unit design are incorporated in them.

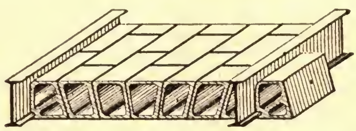
The development of the structural clay tile industry in the United States was rapid and production quickly spread from New Jersey to other clay producing areas. Reis and Leighton outline this growth from 1875 to 1909 (the date of publication) as follows:

"Ohio was not far behind New Jersey, and in 1884 fireproofing was much used, being made at Toronto and Columbus. Hollow blocks at that time, however, were only being turned out at one locality, in Summit County. Terra cotta lumber was made in Illinois as early as 1884.

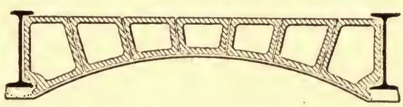
"In 1885 fireproofing manufacture began in Indiana, and has continued up to the present time, while a large local industry was started on the surface clays at Hobart, Indiana, in 1887, and has there undergone great expansion. During the '90s factories for making fireproofing or hollow blocks sprang up at a number of points and became active and successful producers, those located near the great markets being often run to the limit of their capacity.



View of 9 in. Tile Arch, between 10 1-2 in. I beams.
Weight 38 lbs per square ft.



View of 12 1-2 in. Tile Arch between 15 in I beams.
Weignt, 45 lbs per square ft.



Section through Hollow Tile Floor Arch
with Concave Soffit.

FIG. 1-2
Early designs of hollow tile arch floors

"It is to be noted that the most important producing districts are not far from the large markets, as the cheapness of the ware does not permit long hauls. Clays of suitable character for hollow blocks, etc., are not hard to find, and almost every state contributes to the total production, and supplies a local demand.

"An important step in 1899 was the incorporation of the National Fireproofing Company of Pittsburgh, Pa., which took over a number of works located in Pennsylvania, Ohio, New Jersey, Massachusetts, and Maryland, most of which have continued in operation.

"At the present day, New Jersey, Ohio, Indiana, Illinois and Pennsylvania are the more important producers of fireproofing, while Ohio, New Jersey, Indiana and Iowa are the leading producers of hollow blocks and hollow building tile."

In 1903 the National Fireproofing Corporation of Pittsburgh published a Handbook and Catalogue by Henry L. Hinton, illustrating the products of the company and presenting data for use in the design of segmental and flat arch floors. This catalogue is of historical interest, particularly because of the large number of unit designs illustrated. Literally hundreds of different shapes are shown for use in the construction of tile floor arches, partitions and walls and for fireproofing columns, beams and girders.

The number of different structural clay tile shapes and sizes produced by the industry probably reached its maximum about this period and, as experience was obtained in the manufacture and use of the different units, the designs which could be produced most economically and which gave best performance were retained and alternate designs discarded. This process of standardization is being continued by the industry with a constant decrease in stock items.

During the period since 1899 the structural clay tile industry has become an important part of the clay products industry of the United States.

FIG. 1-3

Structural clay tile barracks at Ft. Benning, Ga.

In the tremendous Federal construction program which followed the passage of the Selective Service Act in 1940 and the Declaration of War in 1941, structural clay tile was used extensively and, after lumber became critical, it was largely relied upon for all types of buildings. Brick and tile were used for the construction of mobilization structures, war housing, defense plants, air fields, and buildings at Army and Navy bases. Fig. 1-3 and 1-4 illustrate some of these structures constructed of structural clay tile.

As previously indicated, structural clay tile are essentially hollow units and the first product was known as hollow tile. After the invention of terra cotta lumber, hollow tile were also referred to as terra cotta tile or terra cotta fireproofing and are so designated in the 1903 catalogue of the National Fireproofing Corporation.

Fig. 1-4

Structural clay facing tile buildings at WAC Training Center, Ft. Des Moines, Iowa

In 1921 the American Society for Testing Materials proposed standard definitions of terms relating to "Hollow Tile", in which the units were designated as hollow tile and defined as "hollow burned clay masonry units with parallel cells." These definitions were adopted as standard in 1924 but were later withdrawn and in 1933 standard definitions of terms relating to structural clay tile were proposed in which the units were designated as structural clay tile and defined as "hollow burned clay masonry building units with parallel cells." These definitions were adopted as standard in 1936 and remain the recognized terminology of the industry today.

From the foregoing review of the origin of the various products of the heavy clay products industry, it will be seen that brick, terra cotta, tile and drain tile are all of ancient origin and that the terms used to designate these products have come down to us in many languages through hundreds of years. All of these products were molded units of clay or shale hardened by heat. Structural clay tile, the newest member of the group, is a machine made product and essentially a cored or hollow unit.

102. RAW MATERIAL

Clays and shales from which brick and structural clay tile are made are found in many locations all over the world. Nature has, through centuries of time, produced a raw material which might properly be called a mixture of stable chemical compounds. Clay differs from shale, not so much in chemical composition as in physical structure.

The following description of clays and shales and their properties is reproduced from U. S. Department of Commerce Trade Information Bulletin No. 842, "Structural Clay Products" by J. Joseph Palmer:

"Clay (common mud to many) suitable for manufacture into brick and tile is a bewilderingly complex material. Technically known as a hydrated silicate of alumina—AL_2O_3, 2 SiO_2, $2H_2O$—in which may occur such sundry intermingled impurities as oxides of iron, calcium, magnesium, potassium, sodium, titanium, and sulfur, this clay is the disintegrated remains of feldspathic rocks, themselves the product of the earliest periods of the formation of the earth. In the millions of years that have intervened, a part of this clay has lain at its original site, and other parts have been torn away by glacial movements and successive winds, rains, and floods, to be deposited at various levels and distances as sediment on the beds of rivers, lakes, and oceans. The products resulting from such evolutions comprise three groups: (1) Surface clays, which may be either the upthursts or intrusions of older deposits or those of more recent formation and sedimentary in character; (2) shales, materials which have over the ages been subjected to intense pressures until the basic clay has almost been reduced to the form of slate; and (3) fire clays, which are mined at deeper levels and are so-called because of their refractory qualities.

"The uses to which clay can be put are determined to a very large extent by its natural properties. These may be divided into two general groups—physical and chemical—each being so dependent upon the other as to make it difficult to say which is the more important. Not only do these properties determine what may be made of the clay, but they largely dictate the manufacturing processes which may be employed and the color and finish of the completed product.

"Among the physical properties which must be considered if a clay is to be suitable for manufacture into brick and tile are: Plasticity, shrinkage, tensile strength, and fusibility. Plasticity is that property by means of which clay forms a plastic mass when mixed with water—which permits it when so mixed to be molded into a predetermined shape and to retain that shape after the greater part of the added water has evaporated. Various clays are plastic in different degrees, some being highly plastic whereas others possess this quality to only a very limited extent. The manufacturer of structural clay products may, of course, use either type, or he may blend two or more kinds until a material of the desired degree of plasticity, and of low shrinkage is obtained.

"Shrinkage is a property possessed to some degree by all clays; those displaying the least shrinkage are the most preferred by the clay-products manufacturer. Shrinkage is of two recognized types—air shrinkage which takes place after the clay product has been formed and before it is placed in the kiln for firing, and fire shrinkage, which, as the name implies, occurs during the process of burning. Either, if excessive, may be the cause of cracking or warping, so that it is customary to seek a plastic mixture of

low shrinkage which will result in a finished product uniform both as to dimension and texture."

Author's Note: Shrinkage, both air (dryer) shrinkage and fire shrinkage, varies for different clays. However, for most clays used commercially in the production of brick and tile, it will fall within the following ranges:

Air Shrinkage per cent	Fire Shrinkage per cent	Total Shrinkage per cent
2—8	2.5—10	4.5—15

The problem that confronts the clay manufacturers in the production of brick or tile of uniform size and shape is not so much the total shrinkage of the clay which may be compensated for in the size of the dies or molds, but the variation in shrinkage of the clay or shale from the same clay bank or mine. This variation will depend upon the purity of the clay deposit, variation in moisture content of the green ware and differences in firing temperatures.

"Tensile strength of the clay is that quality which resists the tendency of the formed clay products to rupture, especially while in the air-dried state. Although this bears no definite relation to the strength of the burned product, it is of utmost importance during the period between forming and burning in order to facilitate handling and stacking.

"Clays, unlike metals, soften slowly and melt or fuse gradually when subjected to rising temperatures. It is this property of clay, its fusability, which causes it when properly burned to become hard, solid, and substantially nonabsorbent. Fusing takes place in three stages: Incipient fusion, that point when the clay particles become sufficiently soft so that the mass sticks together; vitrification, when there is extensive fluxing and the mass becomes tight, solid, and nonabsorbent; and viscous fusion, the point when the clay mass breaks down and tends to become molten. The manufacturer's problem is to so control the temperature in the kiln that incipient fusion and partial vitrification are complete and viscous fusion is avoided.

"So much for the physical properties of clay. As to the chemical properties, these determine to a great extent the color and fusibility of the product. For example, iron oxide in the clay tends to color the finished products in the range of reds, browns, and buffs, whereas clays free of this material usually burn to a white or a cream color. Lime if present in sufficient quantities will produce a generally similar result, since it overcomes any iron oxide present and produces cream or buff-colored brick and tile. The effect of these materials does not stop here, for, being fluxes, they lower the fusing point of the clay well under the temperatures required to fuse material in which they are not present.

"Any carbonaceous matter in clay must be eliminated. This is accomplished by combustion, which necessitates the presence of oxygen. The necessary oxygen may be present in the atmosphere within the kiln, or it may also be obtained from any ferric oxide present in the clay itself. The oxygen enters into a combustible combination with the carbonaceous matter. Burning or firing of the clay converts ferric oxide into ferrous oxide, and the

TABLE 1-1
CHEMICAL ANALYSIS OF CLAYS

Source	Kind of clay	Nonvolatile Constituents										Total loss on ignition Percent (2)	Total flux(3) Percent
		SiO_2 Percent	Total iron as Fe_2O_3 Percent	Al_2O_3(1) Percent	Mn_3O_4 Percent	P_2O_5 Percent	CaO Percent	MgO Percent	Na_2O Percent	K_2O Percent	SO_3 Percent		
b	Shale	56.0	4.9	20.6	Tr.	.10	7.2	4.7	.1	4.7	1.1	12.7	21.70
c(5)	Shale	60.3	6.5	20.4	.06	Tr.	3.4	2.8	.92	4.8	.87	1.8	18.48
c-1(5)	Shale	60.4	6.0	18.5	.03	.44	4.9	3.6	.95	4.5	.52	1.3	20.42
d	Shale	61.4	8.6	19.2	.06	1.6	1.1	2.4	.88	4.3	.69	6.2	18.94
d-1(5)	Shale	65.2	7.2	18.7	.03	.11	.20	2.2	1.9	4.4	.27	1.2	16.04
d-2(5)	Shale	67.8	5.8	19.2	.04	.06	.80	1.8	2.4	2.4	.14	.40	13.30
d-3(5)	Shale	64.8	7.5	21.3	.03	.08	.80	1.7	1.6	2.8	.27	.46	14.51
e	Shale	63.5	6.8	18.7	Tr.	1.6	.53	4.0	1.1	3.0	.26	12.3	17.03
f	85 per cent fire clay, 15 per cent shale	63.8	1.9	30.4	Tr.	.14	.34	.89	.36	1.8	1.2	9.6	5.43
g	50 per cent shale, 50 per cent fire clay	66.4	5.8	21.3	Tr.	1.4	.19	1.4	.50	3.2	.26	6.4	12.49
h	Fire clay	69.6	.22	29.1	.08	Tr.	.22	.40	.14	.33	.37	9.1	1.39
j	Surface clay	60.8	6.1	16.9	.04	.31	6.8	2.9	1.4	3.0	1.2	5.2	20.55
k	Surface clay	64.6	8.2	21.8	Tr.	.16	.34	1.3	.68	1.8	4.1	11.2	12.48
k-1(5)	Surface clay	66.7	6.0	16.7	.03	.21	3.0	2.7	2.4	2.7	.17	.98	17.04
k-2(5)	Surface clay	70.4	6.6	17.0	.05	.12	1.0	1.1	2.6	1.3	.12	.40	12.77
k-3(5)(6)	Surface clay	67.4	5.7	14.9	.02	.18	5.9	2.1	1.6	2.4	.66	1.1	17.90
l	Fire clay	61.8	4.7	27.9	Tr.	.37	.44	.84	.60	2.3	3.8	10.5	9.25
l-1(5)	Fire clay	64.4	2.3	28.2	Tr.	Tr.	Tr.	.96	1.4	3.0	.19	.32	7.66
l-2(5)	Fire clay	71.5	3.3	22.4	.01	Tr.	.78	.51	1.3	.56	.19	.26	6.46
m	Fire clay	66.8	1.6	28.9	Tr.	Tr.	.60	.40	.65	.98	1.2	8.0	4.23
n	Fire clay	72.5	3.8	19.8	Tr.	.40	.21	.56	.54	1.9	1.2	6.6	7.41
o	Surface clay	57.8	.81	20.4	.06	.40	9.8	5.6	.76	3.9	.45	13.9	21.33
o-1(5)	Surface clay	60.9	5.1	12.8	.04	Tr.	8.8	5.6	2.1	3.9	.85	1.3	25.54
p	Fire clay	67.8	2.4	25.2	Tr.	Tr.	.39	.33	.38	2.4	2.5	9.4	5.90
p-1(5)	Surface clay	64.6	6.8	24.1	.03	.12	.14	.94	1.7	1.8	.14	.70	11.53
q	Surface clay	60.2	5.3	22.8	.09	.50	1.5	2.7	2.2	4.0	.16	4.0	16.29
r(5)(7)	Surface clay	75.6	1.9	9.4	Tr.	Tr.	(8)	.37	.97	2.2	.08	.44	5.44

(1) Al_2O_3 figure includes any TiO_2 that may be present.

(2) This figure represents total loss on ignition at the temperature of the blast and is the algebraic sum of the various changes, including loss of CO_2. (See W. F. Hillebrand, U. S. Geol. Surv. Bull. 700, 231 and J. W. Mellor, Treatise on Quantitative Inorganic Analysis, pp. 157-159). The results for samples k, l, m, n, and p are apparently too high, probably owing to the reduction of sulphate to sulphide by the organic matter present.

(3) Total flux includes Fe_2O_3, Mn_3O_4, P_2O_5, CaO ,MgO Na_2O, and K_2O.

(5) Analysis made on the burned clay. All others on the raw clay. Organic matter detected in all samples of raw clay. Appreciable amount being present in samples f, g, h, j, k, l, m, n, and p.

(6) Actually a weathered shale.

(7) Actually a mixture of pottery clay, fire clay, and fire sand. Analysis applies for tile in tests 40 and 41.

(8) Not detected.

TABLE 1-2

SOFTENING POINTS OF CLAYS

Source	Kind of clay ①	Softening Point		
		Cone No.	°C.	°F.
b	Shale		1,140	2,084
c	Shale		1,145	2,093
c-1	Shale	1	1,160	2,120
d	Shale		1,180	2,156
d-1	Shale	3	1,170	2,138
d-2	Shale	7	1,250	2,282
d-3	Shale	9	1,285	2,345
e	Shale		1,240	2,264
f	15 per cent shale 85 per cent fire clay		1,390	2,534
g	50 per cent shale 50 per cent fire clay		1,325	2,417
h	Fire clay	19	1,515	2,759
j	Surface clay		1,170	2,138
k	Surface clay		1,335	2,435
k-1	Surface clay	2	1,165	2,129
k-2	Surface clay	8	1,260	2,300
k-3	Surface clay	3	1,170	2,138
l	Fire clay		1,350	2,462
l-1	Fire clay	18	1,490	2,714
l-2	Fire clay	19	1,520	2,768
m	Fire clay	20	1,525	2,777
n	Fire clay		1,390	2,534
o	Surface clay		1,130	2,066
o-1	Surface clay	2	1,165	2,129
p	Fire clay	19	1,515	2,759
p-1	Surface clay	17	1,475	2,687
q	Surface clay		1,330	2,426
r	Surface clay	16	1,465	2,669

① The clays designated here as fire clays are not strictly comparable with the true fire clays from which refractories are made. They contain various amounts of impurities, some of which act as fluxes and give the burned clay body the strength necessary for structural purposes.

ferrous oxide, in combination with silica in the clay, forms a fusible ferrous silicate."

Tables 1-1 and 1-2 are reproduced from Department of Commerce Research Paper No. 37, "Fire Resistance of Hollow Load-Bearing Tile" by S. H. Inberg and H. D. Foster, and show the chemical analysis and softening points of 8 shales, 7 fire clays, 10 surface clays and 2 mixtures of fire clay and shale.

These clays and shales were obtained from 25 separate sources in 12 different states, including the principal clay products producing areas of the United States, and are representative of the raw materials now (1950) used for the production of structural clay products.

Total fluxes listed in Table 1-1 include the oxides Fe_2O_3, Mn_3O_4, P_2O_5, CaO, MgO, Na_2O, K_2O, which from a chemical standpoint are impurities in the clay; however, as indicated by the footnote to Table 1-2 these fluxes "give the burned clay body the strength necessary for structural purposes."

In general, it will be noted that shales and surface clays contain high percentages of oxides, ranging from 25.54 per cent to 11.53 per cent. The values listed for source "r" are not included, since, as indicated by footnote 7, Table 1-1, it may not be true surface clay.

Compared to the shales and surface clays, the oxide content of the fire clays is very low, ranging from a maximum of 9.25 to a minimum of 1.39 per cent for the clays analyzed.

As previously indicated, fluxes lower the fusing point of clays. The amount of this reduction may be noted from Table 1-2 which indicates that the softening points of fire clays are consistently higher than the softening points of the shales and surface clays.

In addition to their effect on the softening point, oxides have an important effect on the burning range of clays; that is, the range of temperature in which the material matures; and as previously indicated the oxides of iron, calcium and magnesium particularly influence the color of the burned ware.

103. MANUFACTURE

The invention of brick-making machines during the latter part of the 19th century had a revolutionary effect upon the structural clay products industry, since these machines made possible the manufacture of hollow units of sizes and shapes that could not be produced commercially by hand.

Modern structural clay products are all machine made and in the United States the three most common methods of manufacture are the stiff mud, the soft mud and the dry press processes. Fig. 1-5 charts the flow of clay from pit to finished ware by each of these methods.

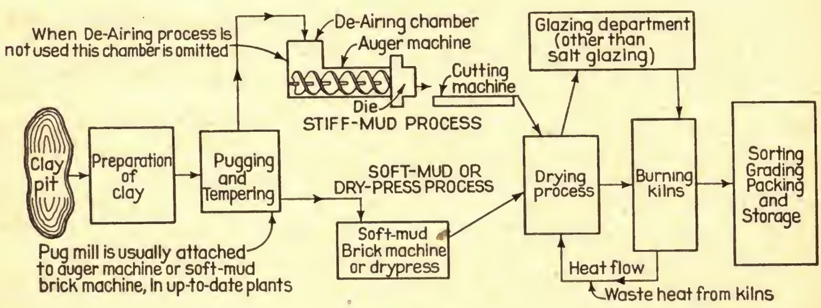


FIG. 1-5

Flow chart showing typical operations in a modern plant for manufacturing structural clay products

The following description of the principal processes in the manufacture of brick and structural clay tile is summarized from an article, "The Manufacture of Structural Clay Products", by F. E. Emery, formerly Engineer-Secretary, Eastern Structural Clay Tile Association.

The fundamental principles of preparing the clay are the same in all three processes, which differ only in details and in degree of refinement, de-

pending to some extent upon the type of finished ware required. The stiff-mud process is used where the clay contains just sufficient moisture (12 to 15 per cent) and plasticity to be extruded through a die. This is the most common method of manufacture, and here the freshly molded, or "green" ware will support considerable weight. All structural clay tile and a great many brick are made by the stiff-mud process. The soft-mud process, on the other hand, is used where the clay is too wet (20 to 30 per cent moisture) to be forced through a die and hence must be molded. The resulting shapes will not support weight. Many millions of brick are made annually in the Hudson River Valley and in New England by the wet process, where the clay is usually wet in its natural state. A third method of manufacture is the dry-press process, where the clay in a nearly dry state (7 to 10 per cent moisture) is molded into desired shapes under high pressure. This process of manufacture makes possible the use of non-plastic materials.

Process of manufacture of structural clay products may be divided into the following steps:

Selection and "winning" of suitable clay.

Storage.

Preparation of clay (cleaning, removing large stones and pebbles, grinding, and screening).

Mixing and tempering to produce plasticity, uniformity, and homogeneity.

Shaping into units by extruding machines and cutters, molds, presses, or other appliances.

Drying, either by natural or artificial means.

Burning, usually in kilns.

"Winning" is the term applied to obtaining the clay from the pit. Clays are mostly reclaimed by surface-digging or quarrying, and to some extent by mining, depending upon the nature and location of the deposit. A machine called the shale planer is sometimes used, but frequently the clay (and particularly shale) is so solidified that it cannot be obtained except by blasting. In some pits the quarrying method is used, the deposits being worked in benches much the same as is done in stone quarries. Fire clay used for the manufacture of such high grade materials as glazed ware frequently has to be mined from some distance below the surface. The development of the clay pit is a very important matter, requiring careful planning which takes into consideration not only the best methods of obtaining the clay, but drainage, transportation, and conservation of materials.

As the clay comes from the pit or storage bins in cars or belt conveyors, it is usually delivered to a machine called the granulator, consisting essentially of a semicylindrical tank within which revolves a steel shaft equipped with knives which are pitched so that they not only break up large chunks of clay and mix and granulate the material, but also function as a screw conveyor, discharging the clay at the end of the machine ready for the next step. (If the clay contains large stones, it is sometimes put through conical rolls which tend to crush small chunks of clay and throw out the stones.) The clay is ready to be ground, if necessary. This may be done in any one of several types of grinders. In this operation, grinding wheels called "mullers", weighing four or five tons each, revolve, crushing and mixing the material. In plants where high grade ware is made, the clay may be screened (if necessary) on fine vibrating screens. In such plants, also, the clay is sometimes heat-treated by passing it through a rotary furnace at about 200° F

After the clay has gone through all the preliminary steps of preparation, it is ready for tempering, the object of which is to bring the clays into a homogeneous plastic mass ready to be molded into units of proper shape. Clay is sometimes tempered by running it through rolls, but more generally this is accomplished by the use of pug mills. A pug mill consists essentially of a chamber within which revolve one or two shafts with blades rigidly attached, which thoroughly mix the material. Water is added if needed to produce the desired plasticity.

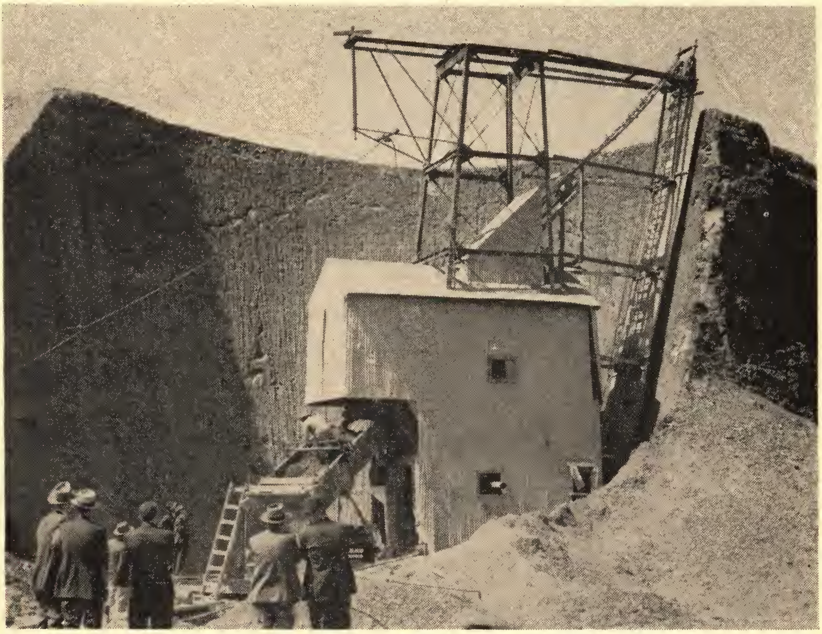


FIG. 1-6

View of deep pit operation showing modern shale planer

In forming the clay into the desired unit shapes, the stiff-mud and soft-mud processes employ different means. In the stiff-mud process of forming and molding, the clay is delivered to an auger machine which forces the plastic mass out through a molding die in a continuous stream called a column. The die molds the mass into the desired shapes for brick, hollow tile, or other forms and as the column is extruded it passes through a machine which cuts it into the desired lengths. In the size of the die and in cutting to length, allowance is made for the shrinkage that will result from drying and burning. After the units are cut to length they pass to a take-off belt for inspection. The perfect units are taken off by hand and sent to the dryer, while the imperfect ones are returned to the pug mill for retempering.

De-airing is an important development in the stiff-mud process. It is accomplished by use of a de-airing chamber attached to the auger machine, through which the clay passes. The clay is broken up and shredded as it enters this chamber, where a vacuum of from 15 to 29 in. of mercury is main-

FIG. 1-7

Mining fire-clay, showing method of drilling blast holes

tained. Some of the chief advantages of de-airing are greater strength in the green and in the fired body, increased workability and plasticity, and better utilization of inferior clays.

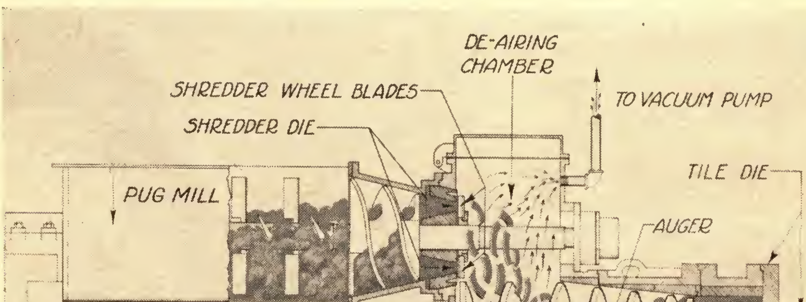


FIG. 1-8

Detail drawing showing pug mill, de-airing chamber and auger machine as used in the stiff-mud process of manufacture

In the soft-mud process, all clay ware is today molded by machinery, except for some special products. In large modern plants, brick are molded under pressure in a soft-mud brick machine which tempers the clay in its pugging chamber, sands the molds, presses the clay into from 4 to 9 molds at a time, strikes off the excess clay, bumps the molds uniformly, and dumps the brick onto a pallet with each revolution. The pallets of brick are carried away to the dryer as fast as made. The operation of the machine is entirely automatic, and the only hand labor used is that required to feed pallets and sand into the machine. There are two classes of soft-mud brick—sand-struck and water-struck. In manufacturing the first kind, the inside of each mold is coated with a thin layer of sand to prevent the clay from sticking. In the second method, also sometimes called slop-molding, the molds are dipped in water to prevent sticking. Sand-molding is the most common method, but some very fine grades of brick are water-struck, particularly in the New England states.

In the dry-press process the clay is usually prepared by disintegrator,

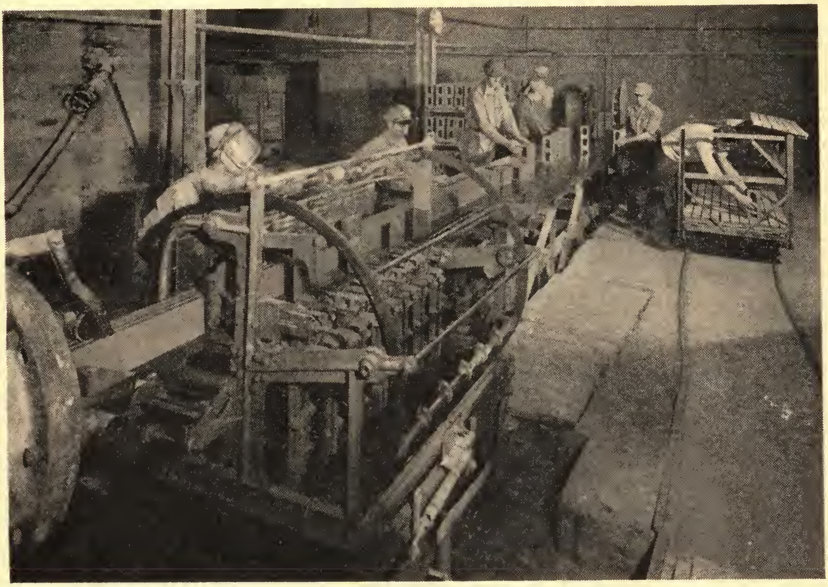


FIG. 1-9

View showing extruded clay column from auger machine at left, passing through cutting table to off-bearing belt

granulator, grinder, and pug mill, and then put into molds and subjected to pressures of from 550 to 1,500 psi. Dry-press brick machines are operated automatically or semi-automatically, and turn out 20,000 to 30,000 brick per day. After the units have been molded, the ware is dried and burned in the same manner as in the stiff-mud and soft-mud processes.

As wet clay units come from the molding or extruding and cutting machines, they contain from about 7 to 30 per cent moisture, depending on

whether the dry-press, stiff-mud, or soft-mud method has been used. Most of this moisture is removed in dryers by evaporation before the burning process begins. Moisture occurs in clay ware in three forms: Free water which fills the pore spaces; water which clings to the pore walls after the free water is removed; and hygroscopic, colloidal, and chemically combined water. The removal of the moisture in the first two forms is accomplished in the drying process and the remainder is removed during the first stages of burning.

There are many different types of driers, but in each the primary object is to remove the moisture from the ware in the shortest possible time, and at the lowest cost consistent with the problem at hand. The heat may be supplied directly or may be waste heat recovered from the kilns. In all cases the heat and humidity of air in the drier tunnels must be regulated so as to avoid spoiling the ware.

Burning is one of the most specialized processes in clay products manufacture, and requires an average time of from 60 to 100 hr. It is done in one of several kinds of kilns, which may utilize wood, coal, natural or artificial gas, or oil. Sometimes electricity is used for burning light special ware.

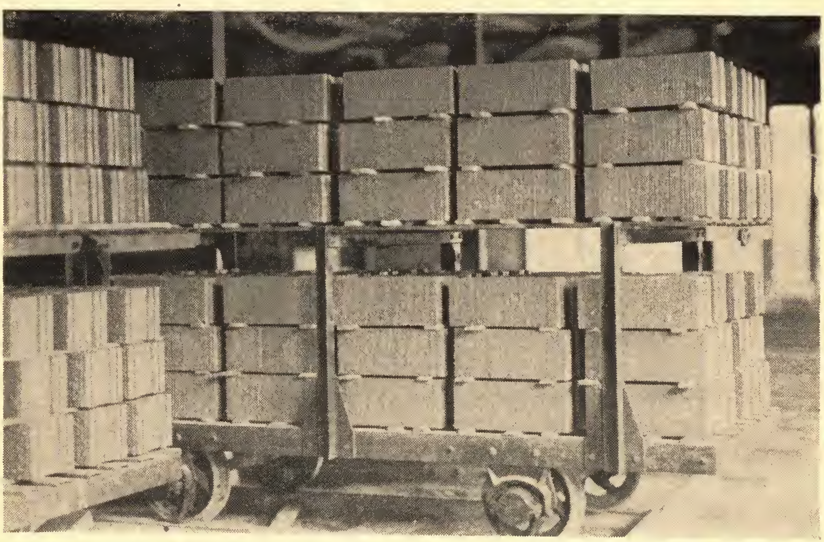


FIG. 1-10

Green ware loaded on drying car

The different stages of burning may be referred to as water smoking, dehydration, oxidation, vitrification, flashing, and cooling. The ware is stacked in kilns in such a way that the hot gasses flow freely around or through the entire mass, and the temperature of each piece can be raised gradually and uniformly. Water-smoking then begins and lasts for from 10 to 12 hr. or more. During this period all free water left in the ware is driven off, under temperatures from 250° to 350°F. As the kiln may contain several hundred tons of ware having from 1 to 2 per cent moisture content, there may be several tons of water to be driven off. This gives some indication of the amount of thermal energy required for water-smoking.

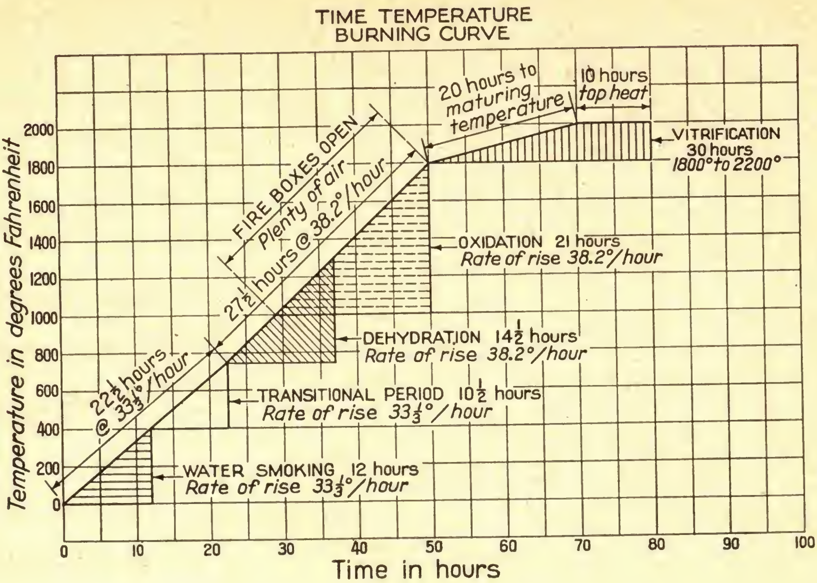


FIG. 1-11

Typical burning chart used in the production of structural clay products

Fig. 1-11 is a theoretical burning chart used in the production of structural clay products. The rate of temperature rise for which best results will be obtained will vary for different clays and shales. Flashing, done by reducing the fire near the end of a burn, produces certain desired colors and shades of colors, varying with different types of clay. This process requires skill and experience with each particular clay. Cooling is not strictly a stage in burning, but is nevertheless important in finishing certain classes of clay. From 48 to 72 hr. are required for proper cooling. The rate of cooling has a direct effect on the color, and too rapid cooling may cause cracking and checking of the surfaces.

A kiln is a furnace consisting of a chamber or series of chambers in which materials are fired or burned. Kilns may be round or rectangular, up-draft or down-draft, periodic or continuous. The chief types in general use for firing structural clay products are scove, muffle, continuous, periodic up-draft, periodic down-draft, and tunnel kilns.

Scove kilns, which belong to the up-draft group, typify an old but very efficient method of burning brick. Dried green brick are stacked up to form an arch. When the fire is introduced, the hot gases travel upward around and between the brick. As many arches as desired can be built side by side. The outside is encased with brick, usually soft-burned from a previous burn, and then plastered with mud to prevent leakage. Scove kilns have capacities of as much as one to two million brick at a burn, but are not suitable for burning high grade ware that requires accurate control of heating and cooling.

The term "muffle" is applied to any kiln equipped with a baffle which prevents the flame from coming in direct contact with the ware. A continuous

kiln has a succession of chambers connected by flues or tunnels in such a way that the hot gases flow through from one chamber to the next. The continuous kiln makes use of a large amount of heat which is wasted in other types.

A periodic kiln is one that is loaded, fired, allowed to cool, and unloaded, after which the same processes are repeated. The terms "up-draft" and "down-draft" are self-explanatory.

The tunnel kiln is built both as a straight and as a circular tunnel, through which the ware passes while being burned. The ware is loaded on special cars, which then enter the tunnel and travel at the correct speed through the water-smoking, dehydration, oxidation, vitrifying, and cooling zones. The heat conditions in each zone are carefully controlled and the kiln operates continuously.

Several kinds of glazing are in general use. Salt-glazing, a very old process, is done by introducing common salt and other chemicals into the fire box near the end of the burn when the ware is approaching incipient vitrification. A salt glaze is a glassy coating formed on the surface of the ware. The vapors from the salt are carried into the kiln, where the sodium comes in contact with the surfaces of the ware and combines with the silica and alumina of the clay body to form a coating. In order to get a uniform glaze, the flow of gases and salt vapor must be carefully controlled by dampers.

Spray-glazing consists of spraying the glazing materials over the ware either before or after drying and before burning. The ware is afterward taken to the kilns for setting and firing. Spray glazes are compounded of a variable number of mineral ingredients in such proportions that at a given temperature they will fuse together in a glass-like coating. Some of these mineral ingredients are feldspar, flint, zinc oxide, lead oxide, calcium carbonate, barium carbonate, and borax. Coloring agents may be added, producing almost any color desired.

CHAPTER 2

MODULAR COORDINATION

201. HISTORY

The coordination of the dimensions of building materials and parts so that they can be assembled during field erection with a minimum of cutting or alteration has long been the dream of those who have made a serious study of the problem of reducing construction costs, and only the multiplicity of parts and the diversity of interest involved have prevented its accomplishment long ago. Building designs, based on the use of such materials, have been variously referred to as modular, rational, coordinated, or by similar descriptive terms.

Although many persons have recognized the importance to the construction industry of coordinating the dimensions of building materials and of correlating building plans with such dimensions, probably the most exhaustive study of the subject was made by the late Albert Farwell Bemis and associates of Boston, Massachusetts. The results of this study are presented in Vol. III, "Rational Design," of the three-volume work, "The Evolving House," published during the period 1933 to 1936. In Rational Design, Bemis suggests a cubical module as the basis for design and develops a method for establishing standard assembly details and a simplified drafting technique in which all dimensions are referenced to a modular grid. The author states: "Fifteen years of study, thought, research, and experiment have established for me the soundness of this elementary approach to building structure—the cubical modular conception."

In the field of masonry, the late Frederick Heath, Jr., was the most outstanding early proponent of modular masonry. In 1923 he was preaching the modular doctrine, and he consistently recommended that dimensions of masonry units be fixed in relation to a standard mortar joint thickness for each type of unit, thus making it possible to standardize masonry dimensions. As an example, his recommended nominal dimensions for brick were 8 in. in length, 4 in. in thickness and 2⅔ in. in height (three courses in 8 in.); for brick laid up in ½-in. joints, the brick dimensions would be 7½x3½x2 1/6 in. Heath wrote and spoke extensively on the subject of masonry dimensions, and his papers still represent advanced thinking on this subject.

Architect Ernest Flagg and others also pioneered in the field of dimensional coordination and Vaux Wilson of the Homasote Company has successfully applied it to the mass production of homes. His publication, "Precision Built Homes," is an authoritative treatise on modular design and construction.

However, the current widespread interest in dimensional coordination, or modular coordination as it is more generally known, stems from the activities resulting from the American Standards Association Project A62 on the Coordination of Dimensions of Building Materials and Equipment.

This project was organized under the sponsorship of the American Institute of Architects and Producers' Council, Inc., in 1939 and was the result of a conference of representatives of all branches of the construction industry called at the instigation of Alan C. Bemis, son of Albert Farwell Bemis, to consider the advisability of such a project.

At this conference Bemis offered the services of the Modular Service Association, organized and supported initially by the heirs of Albert Farwell Bemis, to the project as secretarial and technical staff, and much of the progress that has been made by the ASA Sectional Committee A62, which was organized to develop modular standards, may be attributed to the work of the Modular Service Association.

To date (1950), the American Standards Association has approved four standards on modular coordination: American Standard Basis for the Coordination of Dimensions of Building Materials and Equipment, A62.1-1945; American Standard Basis for the Coordination of Masonry, A62.2-1945; American Standard Sizes of Clay and Concrete Modular Masonry Units, A62.3-1946; and American Standard Sizes of Clay Flue Linings, A62.4-1947.

The structural clay products industry adopted modular sizes for brick and tile as post-war standards in 1943, and subsequent to that time the industry has been converting to the new sizes at an increasingly rapid rate.

At the present time (1950), manufacturers of approximately 50 per cent of the total production of brick and tile in the United States have either converted entirely to modular sizes or are in the process of doing so.

While it will require some time for the entire industry, which consists of about 670 different manufacturers, many of them operating very small plants, to convert to the new sizes, the progress the industry has already made in this direction assures the availability in all markets of modular brick and tile.

Manufacturers of concrete masonry units and of clay flue linings are in the process of converting to the modular sizes and reliable estimates indicate that from 40 to 60 per cent of the national production of these products is modular.

The Metal Window Institute and the National Woodwork Manufacturers Association have developed modular sizes of metal and wood windows and doors, and most types of solid section steel windows and double-hung wood windows (1⅜-in. sash) are produced in modular sizes.

Many other products, such as structural lumber, glass block and insulation, have for years been produced in sizes which coordinate with other modular products and it is now (1950) possible in most markets to obtain the modular building products required for the construction of the complete shell of a building as well as some items of finish and equipment.

202. NEED FOR COORDINATION

The primary objective of Modular Coordination is to reduce construction costs and the methods recommended for accomplishing this are to size manufactured building products, whose dimensions are pre-determined, so that they will fit together without alteration on the job-site and to dimension building plans so that the building dimensions are correlated with the standard sizes of building products.

These procedures are essential to mass production and have come to be accepted as necessary if the current relationships between wage rates and prices of manufactured articles are to be maintained. No one, for example,

would expect to buy an automobile with a door 2 in. wider than the standard at the same price as the stock model, yet such variations constantly occur in the building industry. This lack of consistent practice in the construction of buildings is due primarily to the fact that in the past the sizes of building products have not been coordinated and, consequently, the economies resulting from the use of stock sizes, without alteration, have never been fully realized.

In the past, the standard length of non-modular brick has been 8 in. and when laid up with a ½-in. joint, the distance center line to center line of joints was 8½ in. The length of backup tile used extensively with brick was 12 in. which, with the ½-in. joint, gave a center-line distance of 12½ in. Obviously, it was difficult, if not impossible, to coordinate these dimensions so that a window opening would be an exact multiple of 4¼ in. (one half brick plus one half joint) and at the same time a multiple of 6¼ in. (one half tile plus one half joint), and even if such an opening were obtained, few if any stock windows would fit into it. As a result, it was necessary to redimension masonry units on the job by cutting to fit around the window.

The same condition prevailed when the architect attempted to correlate his over-all building dimensions with the dimensions of the masonry units. In many instances composite walls are constructed of three types of masonry units whose non-modular dimensions, center line to center line of mortar joints, are: Exterior facing brick, 8⅜ in.; backup tile, 12½ in.; glazed facing tile, 12¼ in. To establish over-all building dimensions, which were exact multiples of one-half of these dimensions and, at the same time, would meet the requirements of the building, was usually impossible and, as a result, few architects attempted to do so. The coordination of masonry unit heights presented the same problem as the coordination of their lengths.

As a result of this lack of coordination, experiments, conducted both in this country and in England, indicate that masons spent from 10 to 30 per cent of their time cutting masonry units to fit around openings and to conform to over-all building dimensions.

Recent studies of the comparative masons' time required to construct identical small masonry homes of modular and non-modular units are reported by the Small Homes Council, University of Illinois, in Technical Series E2.11R, "A Study of Non-Modular Masonry Construction." The abstract of this report states:

"In 1947, the Small Homes Council made a detailed study and comparison of construction methods used in residential building. Included in this study was an analysis of three houses in which modular brick were used in the exterior cavity-type masonry wall. No comparison has been available between the data so obtained and the time required to construct the same wall using non-modular materials.

"To obtain such data, the Small Homes Council, under the sponsorship of the Structural Clay Products Institute in 1949 built an exact duplicate of one of the houses constructed in the 1947 study, but used a non-modular brick instead of modular.

"An analysis of the time-study data taken during the construction period indicates that the masons' time can be reduced approximately 10 per cent through the use of modular materials. Furthermore, an examination of the brickwork indicates that an improvement in workmanship is possible through the use of

modular materials. This improvement in workmanship is obtained through the regularity achieved by the use of modular materials."

The non-modular brick used in the construction of the University of Illinois 1949 house were slightly larger than the modular brick used in the 1947 houses; the brick requirement for 100 sq. ft. of 4-in. wall being 617 non-modular and 650 modular. However, in spite of the fact that the masons laid more units, the ease in laying out the work and the reduction of cutting resulted in a saving of approximately 10 per cent of the masons' time.

Most architects and engineers and many contractors and builders are familiar with the objectives of modular coordination and the general principles involved in applying it to building materials and designs. However, since the terms used in modular standards and the techniques prescribed for applying modular coordination to building design are unfamiliar to many in the building industry, there has been a tendency on the part of some to consider the application of modular coordination both involved and complicated and as requiring more time on the part of the architect to develop the plans and on the part of the contractor to execute them than conventional procedure.

Dimensional coordination is not new but must be accomplished whenever a building is constructed and modular coordination, instead of complicating the procedure, simplifies it, both for the architect and the builder.

In the introduction of the "A62 Guide for Modular Coordination," by Myron W. Adams and Prentice Bradley, published by the Modular Service Association, the authors state:

"Dimensional coordination is one of the essential processes of building. However it is done, materials and equipment must be sized at some stage in their design, manufacture or field erection, so as to produce the building called for in the plan. Fundamentally, there is involved a coordination between the sizes of interfitting parts in the structure, and a correlation of the dimensions of the building with their sizes.

"While this process of coordination is common to all building, there is a distinction of basic importance in the methods by which it is accomplished. The fashioning of the component parts of the building in their coordinated sizes may be a shop or factory operation, or it may be accomplished during field erection by cutting and fitting. Often it is a combination of both, started in the factory and completed in the field.

"The architect by his plans, details, and specifications, dictates the methods to be used. He fixes the dimensions of the building, specifies the materials to be delivered, and shows, by assembly details, how particular parts are to be combined. The assembly details may serve as instructions for the shop, for the builder or for both. With many types of construction, however, these instructions have seldom been complete, and much of the coordination had to be performed by the builder under the architect's supervision. The amount of refabrication required in the field depends largely upon whether the sizes delivered to the job have been coordinated, and the extent to which the building dimensions have been correlated with these sizes. When the materials have not been previously coordinated, field refabrication is unavoidable."

As indicated, when sizes of building products have not been coordinated, "field refabrication" is unavoidable. For this reason, architects are forced to rely to a greater or less extent upon the builder to coordinate the various products used in a building and it has been practically impossible for the architect to furnish the builder with complete coordinated assembly details. While this

situation may have resulted in less drafting time required for the development of plans, it has necessitated many hours of effort on the part of both architect and builder to coordinate the various sizes of building products on the job and to correlate the over-all dimensions of the structure with these sizes.

Many architects who have adopted modular coordination as standard practice for building layout have reported that, on the first projects to which modular coordination was applied, it required more drafting time than the conventional methods; however, on subsequent projects drafting time was substantially reduced due to the greater familiarity of the draftsmen with the method, to the repetitive use of coordinated details, and particularly to the time saved in checking modular dimensions.

Contractors who have constructed buildings from modular designs have reported both reductions in cost and construction time and substantial improvement in the quality of construction.

203. DEFINITION OF TERMS

The following definitions of terms used in modular standards are reproduced from ASA Standards: A62.1-1945, Coordination of Dimensions of Building Materials and Equipment; A62.2-1945, Coordination of Masonry; and A62.3-1946, Clay and Concrete Modular Masonry Units.

Dimension. Dimension is a lineal measure such as length, width or thickness.

Size. Size is a volume measure which may be expressed as the product of three dimensions, or an area measure which is expressed as the product of two dimensions.

Building Part. Building part is a piece or unit of building material or an item of building equipment.

Detail. Detail is a drawing showing the dimensions for a particular building part or assembly of parts.

Assembly Detail. An assembly detail is a drawing showing the details and methods of joining or combining building parts, either a construction detail which shows assembly of structural parts of materials, or an installation detail which shows the method of installing building parts, such as doors, windows, and building equipment.

Dimensional Coordination. Dimensional coordination is a relationship between the sizes and dimensions of building parts that will permit their assembly during field erection.

Standard Module. A standard module is a unit of 4 in. used as a standard dimensional increment and as spacing in the standard grid.

Standard Grid. A standard grid is a system of rectangular three-dimensional coordinates to which all building dimensions and details are referred. The grid spacing is the standard module, (4 in.).

Modular Detail. Modular detail is an assembly detail referenced and dimensioned to the standard grid.

Grid Line. Grid line is a line of the standard grid.

Grid Dimension. Grid dimension is a dimension between parallel grid lines on a modular plan or modular detail.

Modular Products. Modular products are building parts, the sizes and dimensions of which are established in conformity with the American Standard

Basis for the Coordination of Dimensions of Building Materials and Equipment, A62.1-1945, or the latest revision thereof.

Coordinated Modular Products. Coordinated modular products are building parts, the sizes and dimensions of which are established by supplementary American Standards which conform to the American Standard Basis for the Coordination of Dimensions of Building Materials and Equipment, A62.1-1945, or the latest revision thereof.

Masonry. Masonry is structural material units laid up in mortar.

Masonry Units. Masonry units are manufactured materials, such as brick, concrete block, structural tile, or stone, suitable for the construction of masonry.

Closures. Closures are masonry units having closed end surfaces, used at jambs and exposed wall ends. They are not to be confused with closers which are supplementary length masonry units with or without closed end surfaces used as take-up units in the field areas.

Supplementary Sizes. Supplementary sizes are masonry units used as take-up, one or both of the face dimensions (height and length) of which are greater or less than the corresponding dimensions of the typical unit of the series.

Shapes. Shapes are masonry units of special design for use as corners, closures, bonding units, fittings or decorative panels.

Nominal Masonry Unit. Nominal masonry unit is a measure of the layout of masonry whose outside dimensions are taken between center lines of mortar joints and are equal to the dimensions of the masonry unit plus the thickness of one mortar joint. See Fig. 2-1.

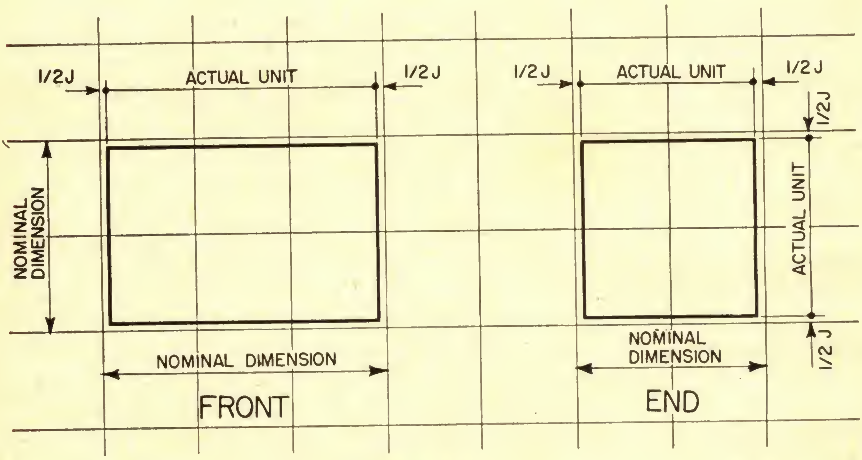


FIG. 2-1

Nominal Masonry Unit

Nominal Face. Nominal face is any face of a nominal masonry unit.

Nominal Surface. Nominal surface is the surface of masonry formed by nominal faces.

Nominal Dimension. Nominal dimension is a dimension between two nominal faces or two nominal surfaces.

Grid Openings. Grid openings are grid lines at openings for items, such as doors or windows, by which these openings are located and dimensioned on plans and modular details.

Structural Clay Masonry Unit. Structural clay masonry units are hollow, cored, or solid masonry units made from clay, shale, fire clay, or mixtures of these materials, and hardened by heat.

Concrete Masonry Unit. Concrete masonry units are hollow or solid masonry units made from portland cement and suitable aggregates, such as sand, crushed stone, gravel, cinders, burned clay or shale, or blast-furnace slag.

Standard Dimension. A standard dimension is the manufacturer's designated dimension.

204. BASIS FOR COORDINATION

The American Standard Basis for the Coordination of Dimensions of Building Materials and Equipment, A62.1-1945, states: "The basis for dimensional coordination shall be the standard grid based on the module of 4 in." This grid is three-dimensional and applies to the height, length and width of buildings.

When the dimensions of buildings are correlated with the 4-in. grid, all grid dimensions will obviously be multiples of 4 in. and the actual dimensions of the building will differ from the grid dimensions usually by not more than 2 in.

Standard dimensions of modular products are also coordinated with the 4-in. grid based on modular details which show the clearances for joining modular products together. Since a joint of definite thickness is required between most building materials when they are assembled to form a structure, the dimensions of modular products are not exact multiples of 4 in.; however, once the required joint thickness, or frame in the case of doors and windows, has been established, successive sizes of the modular unit vary by 4 in. or multiples of 4 in.

In the case of masonry units, the unit dimension plus the thickness of the joint becomes a multiple of 4 in. and, as indicated in Section 203, this dimension from center line to center line of mortar joints is known as the nominal dimension.

ASA Standard A62.1-1945 also provides: "Four-in. flexibility need not apply to the thickness dimensions of walls and floors which may be determined by considerations of economy in the production, distribution and use of materials."

If the nominal thicknesses of floors, walls and partitions were multiples of 4 in., the number of standard sizes of modular products required could be substantially reduced and their assembly greatly simplified. However, obviously, this procedure would not be in the interests of reducing construction costs and, consequently, supplementary units are required where grid dimensions differ substantially from actual dimensions.

205. COORDINATION AND STANDARDIZATION

Coordinating the sizes of building products on the basis of the 4-in. grid does not imply the standardization of product sizes in the sense of a limited

number of stock sizes; however, modular coordination can be an aid to manufacturers in establishing standard sizes for their stock items.

ASA Standard A62.1-1945 provides: "Structural products to be acceptable as coordinated modular products shall provide 4-in. flexibility for building layout", but "modular products, such as windows, doors and equipment, need not provide 4-in. flexibility for building layout. For any one type of product, the differences between the dimensions in alternate sizes shall be multiples of 4 in.; the multiples being determined by practical requirements and economy."

In applying dimensional coordination to building layout, the designer has complete 4-in. flexibility in establishing building dimensions; that is, heights, widths or lengths may vary by 4 in. or multiples of 4 in. However, since few modular products which are produced as standard stock items will provide complete 4-in. flexibility, supplementary or special units will be required for layouts which do not conform to the larger increment, (a multiple of 4 in.) established by the standard modular products to be used in the structure.

If the dimensions of required special units are coordinated with the 4-in. grid on the basis of modular details, their fabrication will be simplfied and, for the particular case, construction costs will be lowered. However, the use of standard stock items will, in most instances, have a greater effect in reducing costs, and, for this reason, building dimensions should be established not only on the basis of a 4-in. increment but also with a view to the standard sizes of materials which will be used in the construction. For instance, the standard sizes of solid section projected steel windows are based on bar center dimensions of 20 in. horizontally and 16 in. vertically. Both a nominal 4-ft. 0-in. high window and a 4-ft. 4-in. high window would conform to the basic requirements of modular coordination. However, since the latter would have to be custom made, its cost would be materially higher than the standard stock item.

In the case of modular masonry, the very popular size of facing tile with nominal face dimensions 5⅓ x 12 in. lays up three courses in 16 in. When this unit is used, if masonry opening heights can be made a multiple of 16 in., savings in construction costs can be effected through the elimination of special sill or lintel units.

206. MODULAR DETAILS

The fundamental basis for modular design is modular details. These details show the relation of the building parts to the 4-in. grid, and thus their relation to each other. This relationship is shown by reference dimensions to the grid lines.

A modular detail may be an assembly detail referenced to the grid or may show the grid location of a single part of the structure, such as walls, floors or partitions. In order to correlate building layouts with assembly details, layout dimensions must maintain the grid positions of the modular details. For this reason, the selection of grid locations of critcal parts of the structure, such as walls and floors, is one of the first decisions to be made in the development of a modular design.

Modular details of alternate grid locations for walls are shown in Fig. 2-2.

Points on grid lines are designated by an arrow and points not on grid lines by a dot. The use of this convention is particularly helpful in determining grid dimensions on small scale drawings where grid lines are not shown.

A symmetrical grid position for walls; i.e., either centered between grid lines or centered on a grid line; has fundamental advantages. In detail 'A'

with the walls centered between grid lines and in detail 'B' with the walls centered on a grid line, the difference between grid dimensions and actual dimensions is a single constant. While in detail 'C' with one wall face on a grid line, there are three alternate values for this difference which must be identified on the plans.

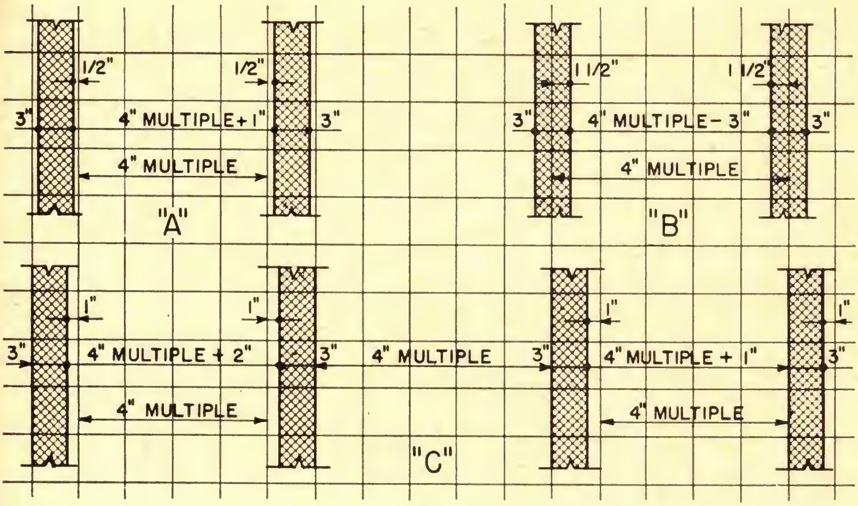


FIG. 2-2

Grid locations of masonry walls

A symmetrical grid position for walls simplifies estimating quantity take-off and the determination of actual dimensions when they are needed. It often reduces the variety of lengths for framing members and other parts.

Opening details involve the coordination of many products, such as modular masonry, both facing and backup, windows, doors, glass block, and trim. Because of the interchangeability provided by coordination, the combinations of particular jamb, head, and sill details, with items installed in the openings, are quite numerous. Consequently, details at openings, and installation details for windows, doors, glass block, etc., are each referenced to the standard grid, permitting them to be drawn as separate modular details. The combination for any one job may then be selected and shown by the architect. Since it is essential for their correct combination that these separate details be referenced to the same grid lines, the grid opening is used and identified by the half-arrow symbol as shown in Fig. 2-3.

The conformation of openings at jamb and head may be flush, or include a recess or chase. The depth of recesses and chases at jambs is 2 in., and, at the head 1⅓ in. or 2⅔ in. The conformation at sills is determined by the window or door installation detail and the sill used.

With flush jambs, when the exterior wall surface is on a grid line, jambs are normally on grid lines, and coincide with the grid opening as in 'A'. When the exterior wall surface is between grid lines, the nominal masonry jambs are between grid lines as in 'B'. The grid opening width is then 4 in. greater

than the nominal masonry opening. With recessed jambs, the width between interior jambs is 4 in. greater than the nominal masonry opening. Consequently, for condition 'A', the width between interior jambs is 4 in. greater than the grid opening, and for condition 'B' it is the same as the grid opening.

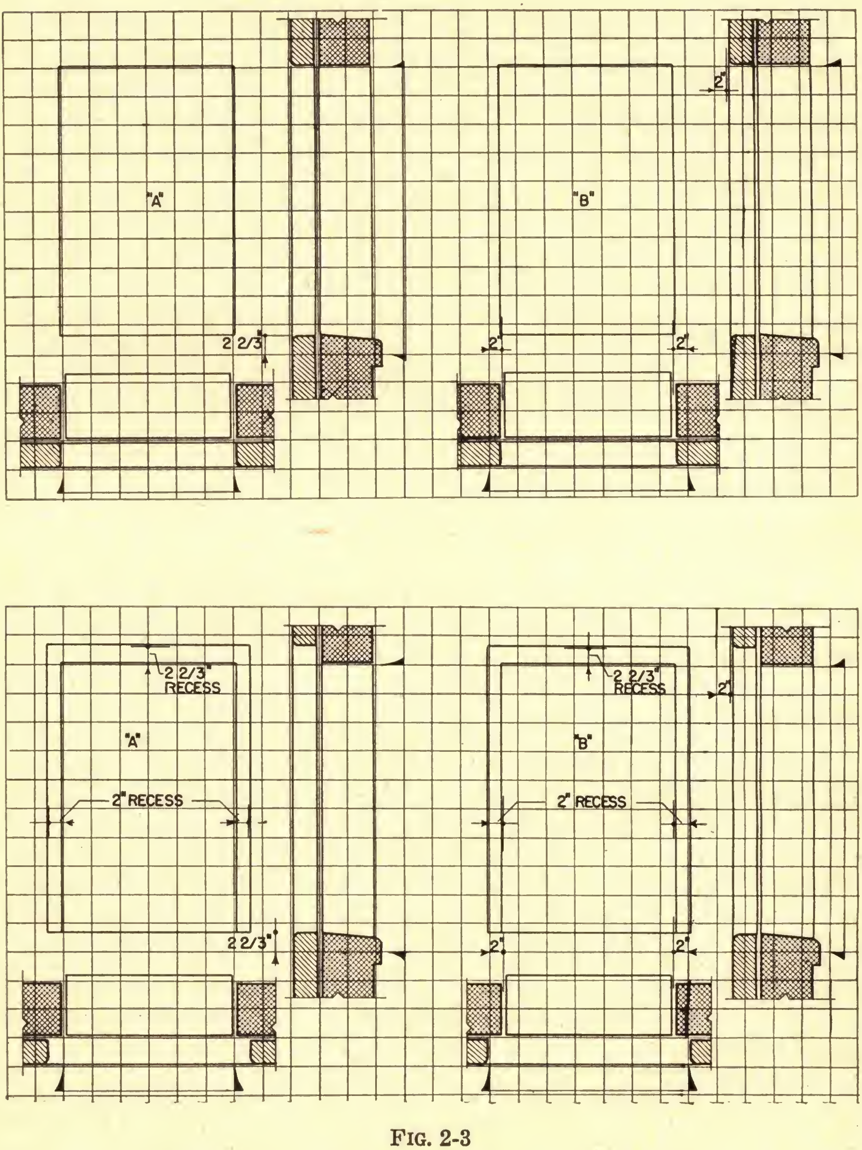


FIG. 2-3

Grid openings

Fig. 2-4 shows modular details of facing tile layouts at heads and sills of openings for various heights and both recessed and flush conditions. Fig 2-5 is a typical modular assembly detail of a solid section metal window in a nominal 12-in. masonry wall with facing tile interior. The height and recess requirements are similar to those illustrated in details D3 and D4 of Fig. 2-4.

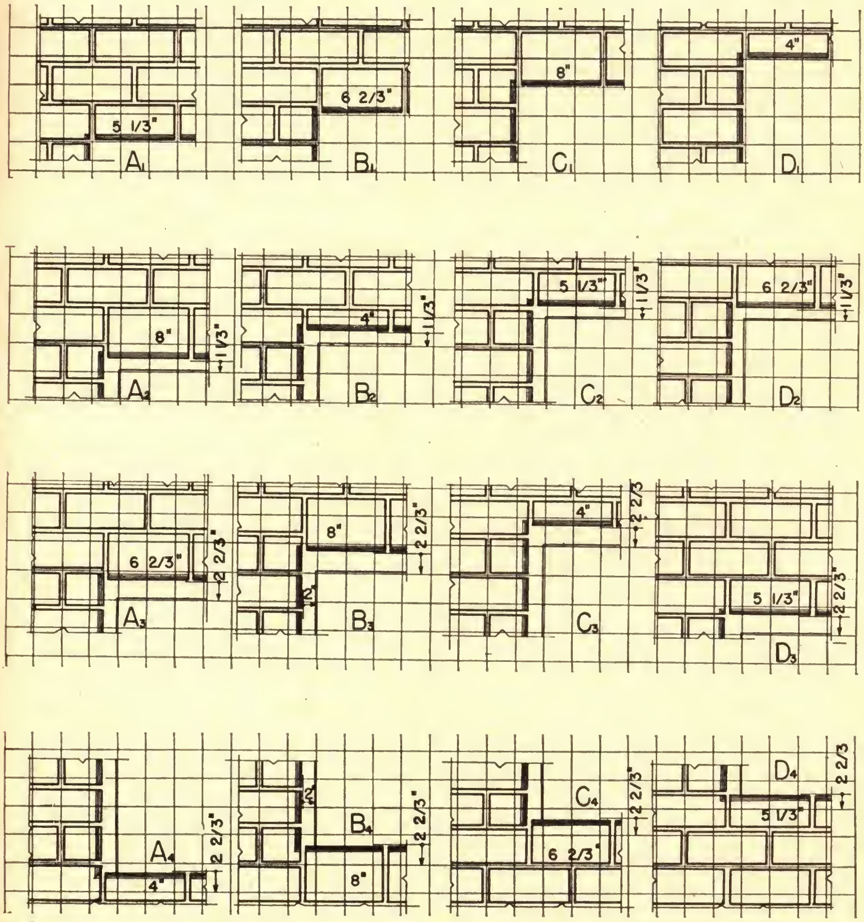


Fig. 2-4

Modular layouts for facing tile lintels and sills

The grid location for floors as recommended in the A62 Guide is: "The surface of finished floors are placed ⅛ in. below the grid line. This applies to all types of floor construction and finishes except wood frame construction in which the wood sub-floors are placed on the grid line. However, with wood joist bearing on masonry, it is better to reference the finished floor ⅛ in. below the grid line in order to maintain a constant relation between the floor and masonry openings for exterior doors."

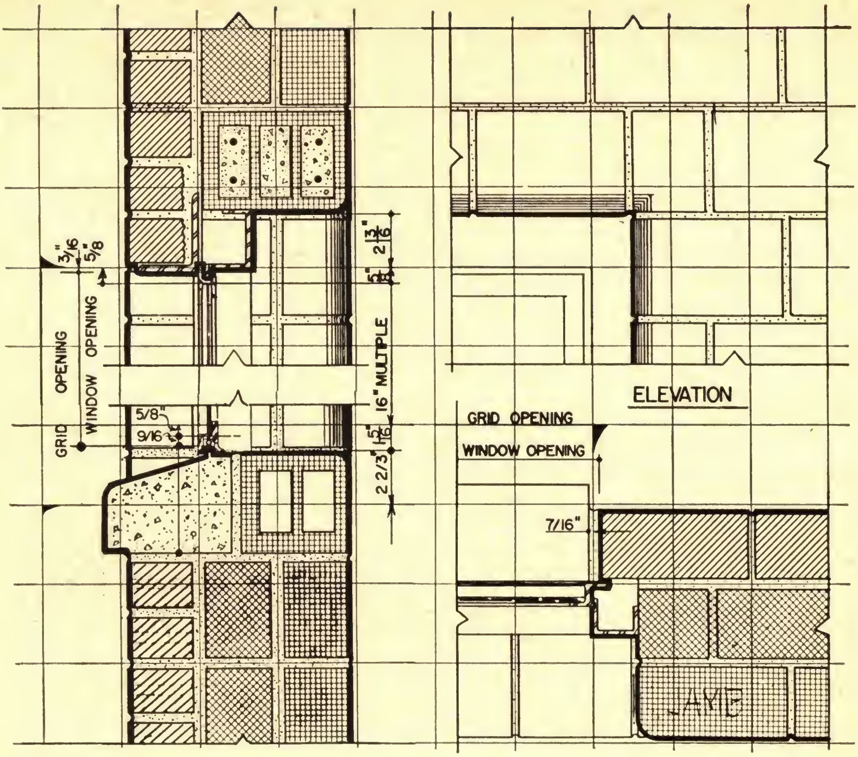


FIG. 2-5

Modular assembly detail

Figs. 2-6 to 2-8, inclusive, are modular details showing the coordination of various types of floor construction with exterior masonry walls.

207. MODULAR MASONRY UNITS

Nominal masonry dimensions which are joint center-line dimensions are used for both horizontal and vertical layouts. The fact that they are independent of the thickness of the mortar joint is a great advantage to the architect.

Horizontal layouts, including wall openings, involve only 2-in. and 4-in. multiple dimensions. Vertical nominal dimensions avoid fractions of inches except for the 2⅔ and 5⅓-in. course heights. Since 3rds of an inch are not given on the ordinary foot-rule, 5/16 in. is used for ⅓ in., and 11/16 in. for ⅔ in. The inaccuracy of this approximation is inconsequential, provided it is not cumulative.

The sizes of standard modular brick and tile are given in Chapter 3, Sections 304 to 306, inclusive.

Nominal lengths are 8, 12 and 16 in., and nominal heights are 2, 2⅔, 4, 5⅓, 6, 8 and 12 in. Few manufacturers will produce all of the sizes listed and it is suggested that the purchaser ascertain the sizes available before proceeding with the design.

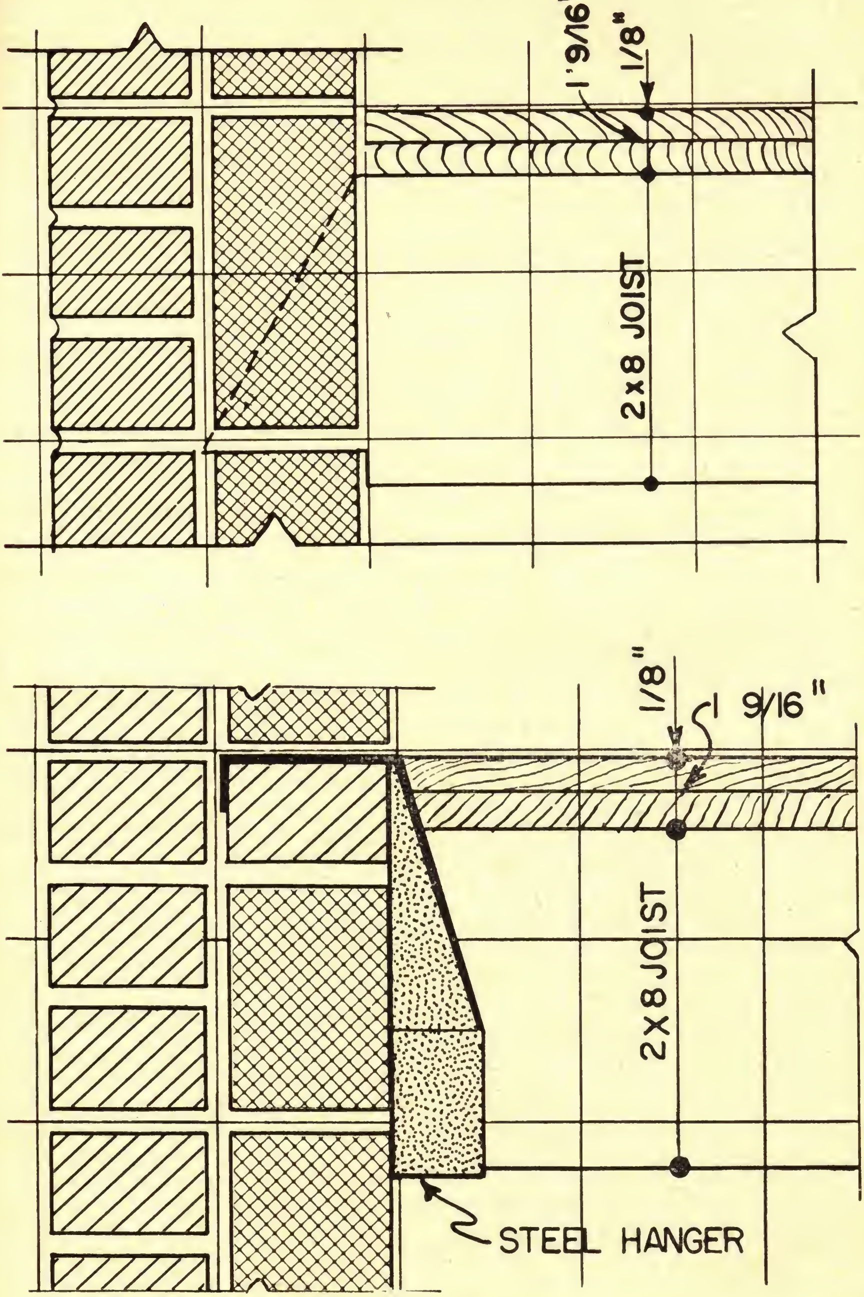


FIG. 2-6

Alternate modular details—wood joist construction

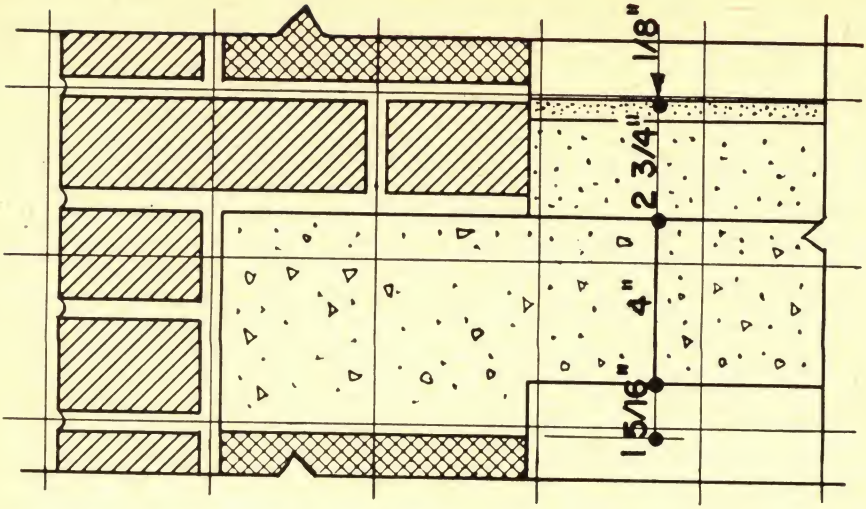


FIG. 2-7

Modular detail—concrete floor construction

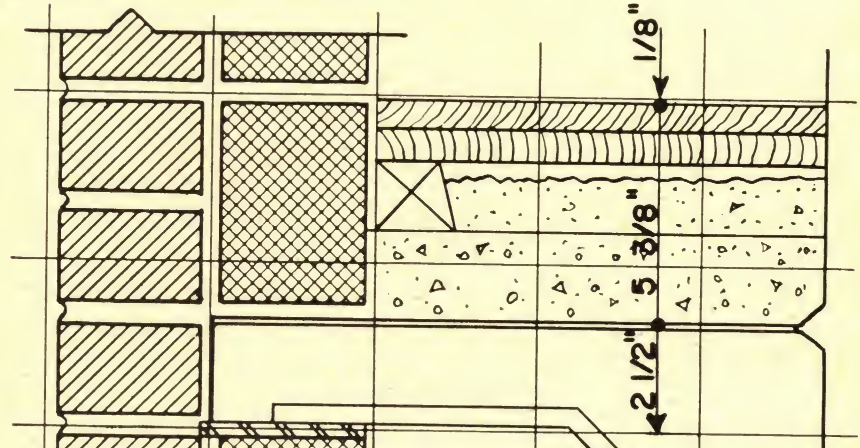


FIG. 2-8

Modular detail—steel joist floor construction

Fig. 2-9 shows the supplementary units required to provide 4-in. flexibility in height for the units listed. It will be noted that all grid lines coincide with horizontal mortar joints only for the 2-in. and 4-in. nominal heights, thus providing 4-in. flexibility without the use of supplementary units.

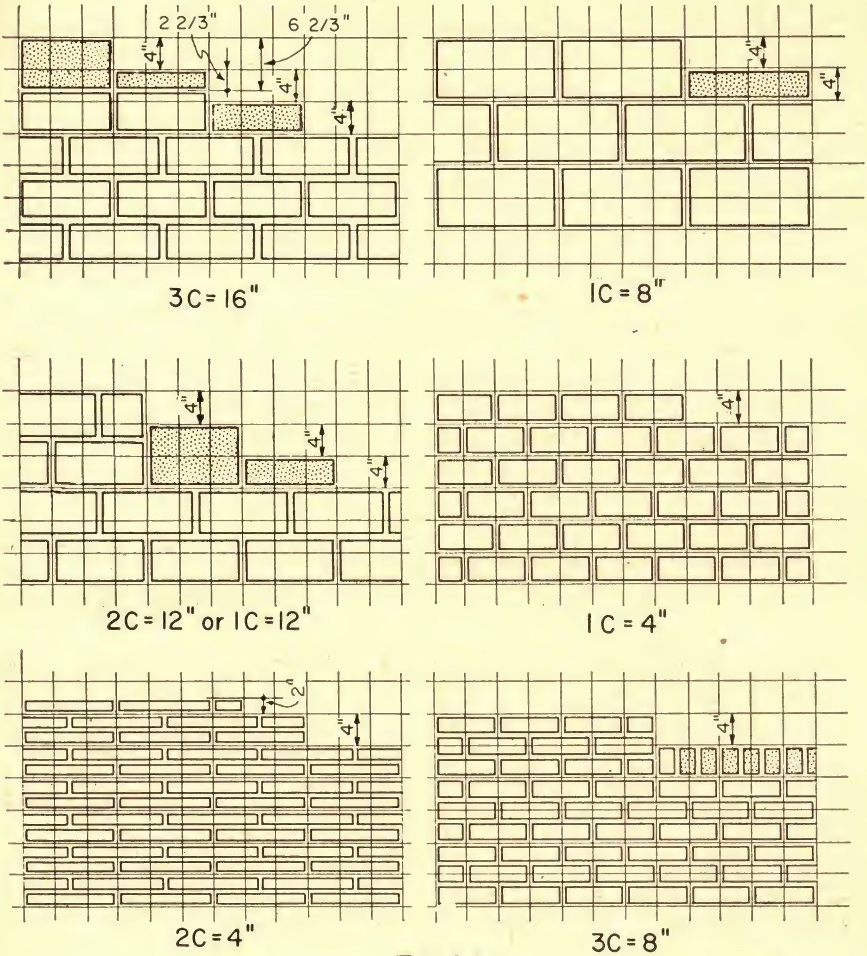


FIG. 2-9

Supplementary units required for 4-in. height flexibility

With the 2⅔-in. unit, grid lines coincide with horizontal mortar joints every 8 in. and a 4-in. supplementary unit is required to provide 4-in. flexibility. This supplementary unit may be obtained by means of a rowlock header course or a 4-in. high supplementary unit.

The fact that alternate grid lines coincide with the mortar joints when the 2⅔-in. high brick is used provides a simple rule for determining the location of a grid line with respect to the masonry at any point above or below a given

reference line. Any grid line which is an even multiple of 4 in. from the reference line will have the same relative position, and any grid line which is an odd multiple of 4 in. will have the alternate position. For example, if it is desired to determine the location of a grid line 7 ft. 4 in. above a grid line which coincides with a mortar joint, it may be found as follows: 7 ft. equals 7 x 3 or 21 modules; 4 in. equals one module. The total, 22 modules, is an even multiple of 4 in.; consequently, the grid line will coincide with a mortar joint.

A similar rule for use with the 5⅓-in. high unit is: A grid line which is an even multiple of 8 in. from the reference line will have the same relative position and any grid line which is an odd multiple of 8 in., an odd multiple of 8 in. minus 4 in., or an odd multiple of 8 in. plus 4 in., will have one of the three alternate positions.

These simple rules greatly simplify the checking of course heights, particularly for lintels where it is usually essential that the head of the opening coincide with a horizontal mortar joint.

As previously indicated, a symmetrical grid location for walls is usually to be preferred to an unsymmetrical position. The correct symmetrical location (centered between grid lines or centered on a grid line) will often be influenced by the length of the masonry units used in the construction.

With masonry units whose nominal lengths are 8 in. or 16 in., vertical (head) joints will occur on grid lines when 4-in. and 8-in. thick walls are centered between grid lines, and head joints will occur at mid-grid points when these walls are centered on grid lines.

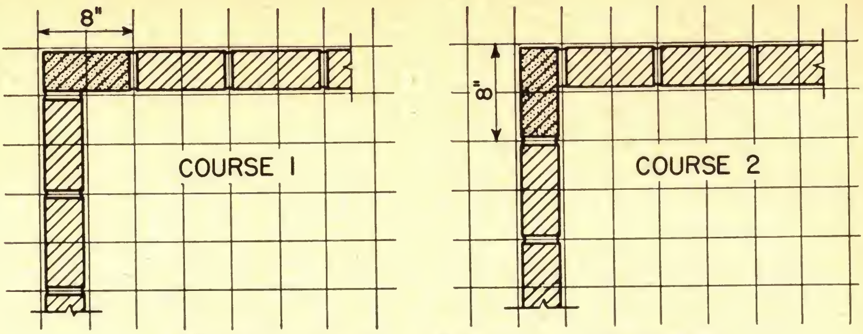
The above conditions are also true for 12-in. nominal length units when laid in ⅓ bond; however, when these units are laid in center bond, vertical joints in alternate courses will occur on grid lines and centered between grid lines.

Fig. 2-10 to 2-14, inclusive, show this relationship for various types of units and wall thicknesses.

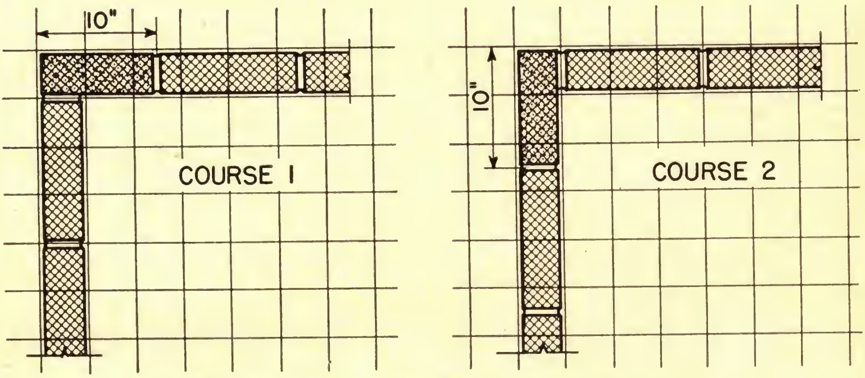
Flexibility in wall lengths may be obtained by supplementary "closure" units at openings or by supplementary "closer" units in the field. These latter units are usually placed at the corner or adjacent to a jamb unit. Since supplementary units in the masonry field tend to destroy the pattern created by the bond, it is desirable, both from the standpoint of appearance and cost, to limit their number to a minimum. This can often be accomplished by making wall lengths a multiple of ½ the nominal masonry unit dimension if the units are to be laid in ½ bond, or ⅓ of this dimension if they are to be laid in ⅓ bond.

Fig. 2-15 to 2-17, inclusive, show the supplementary units required for 4-in. flexibility for the nominal lengths of 8, 12 and 16 in.

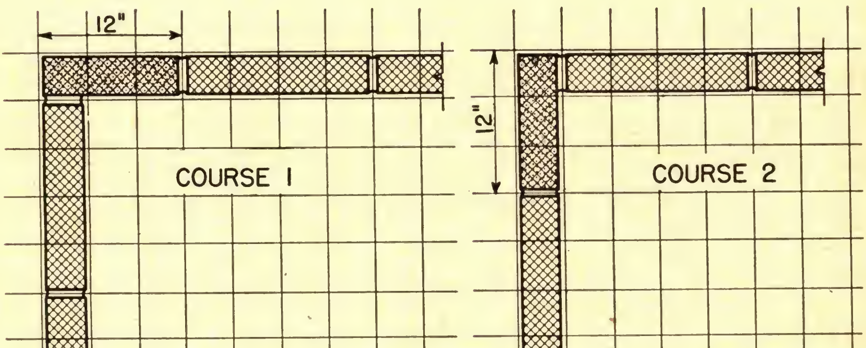
The coordination of different masonry products is shown in Fig. 2-18 in large scale plan and section. The exterior units, designated with the shaded lines to represent brick, are shown with ⅜-in. joints. In the center wythe, cross-sectioned to indicate structural tile, ½-in. joints are shown; whereas the inside facing of glazed tile is laid with ¼-in. joints. The full coordination between units is apparent and, as indicated, the thickness of the vertical or collar joint between different types of units is the average of the joint thicknesses of the two units; 7/16 in. between brick and back-up and ⅜ in. between glazed tile and back-up.



8" STRETCHER - 4" THICK - 1/2 BOND



12" STRETCHER - 4" THICK - 1/2 BOND



16" STRETCHER - 4" THICK - 1/2 BOND

FIG. 2-10

Modular corner details—4-in. walls

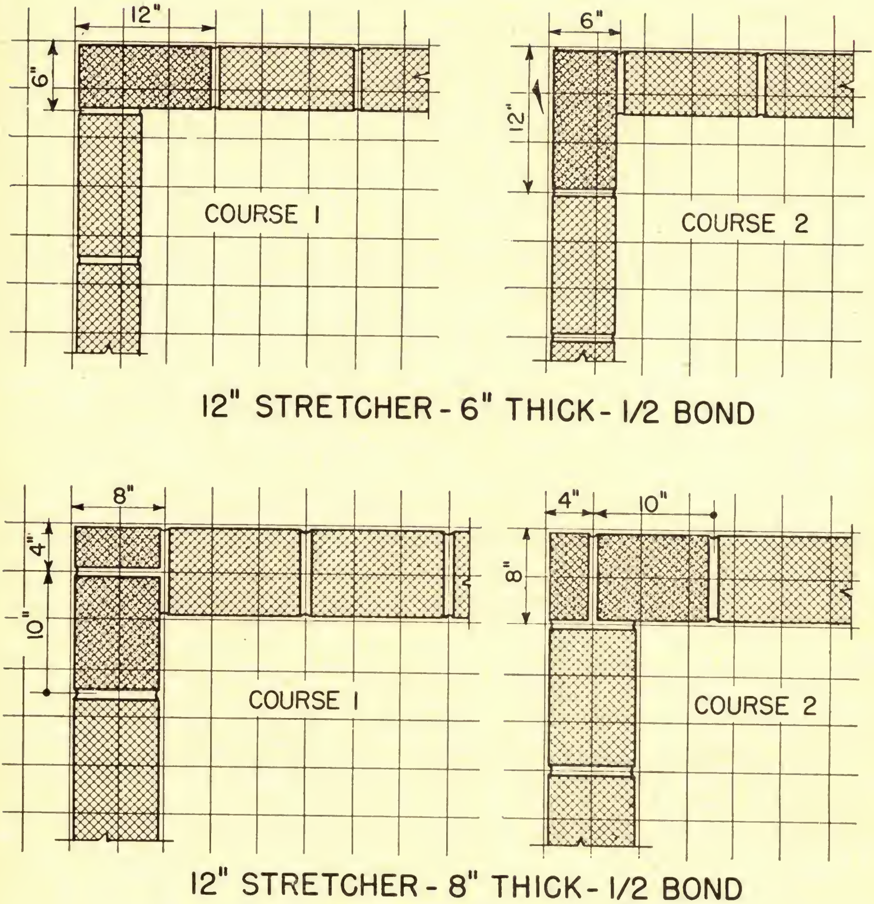
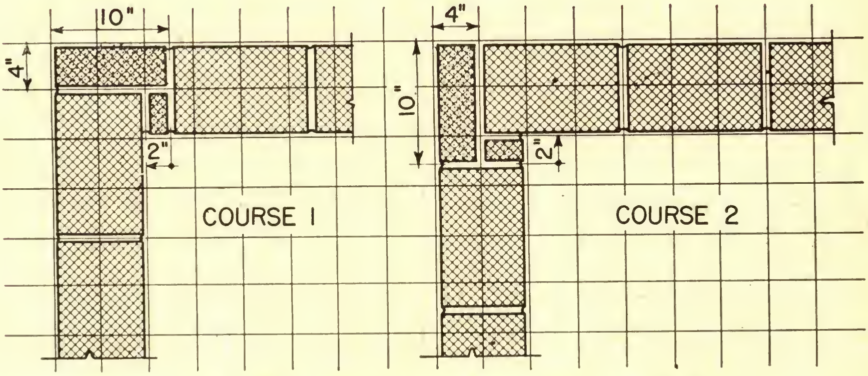
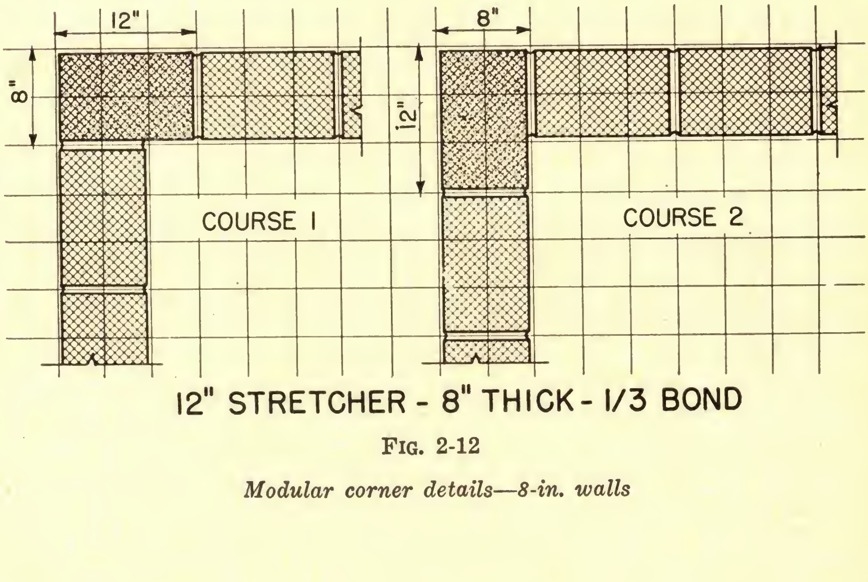


FIG. 2-11

Modular corner details—6-in. and 8-in. walls



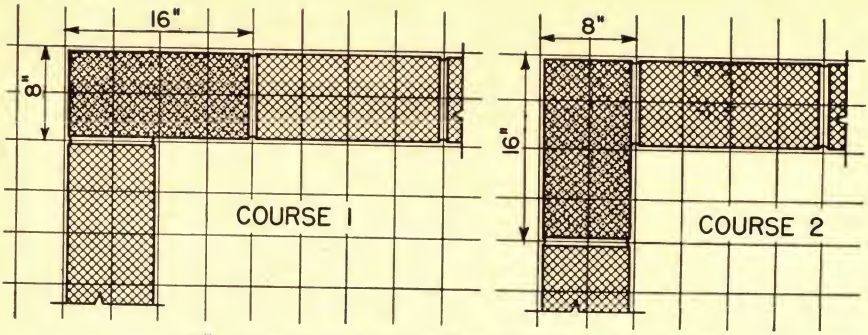
12" STRETCHER - 8" THICK - 1/2 BOND



12" STRETCHER - 8" THICK - 1/3 BOND

FIG. 2-12

Modular corner details—8-in. walls



16" STRETCHER - 8" THICK - 1/2 BOND

Fig. 2-13

Modular corner details—8-in. walls

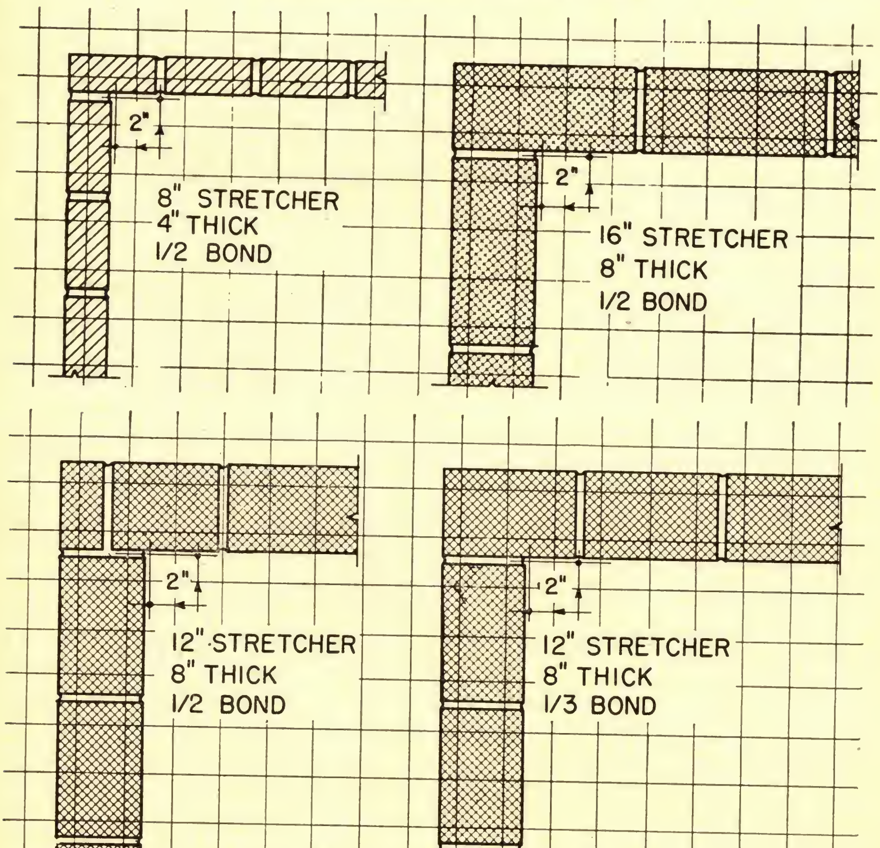


Fig. 2-14

Modular corner details—showing alternate grid locations

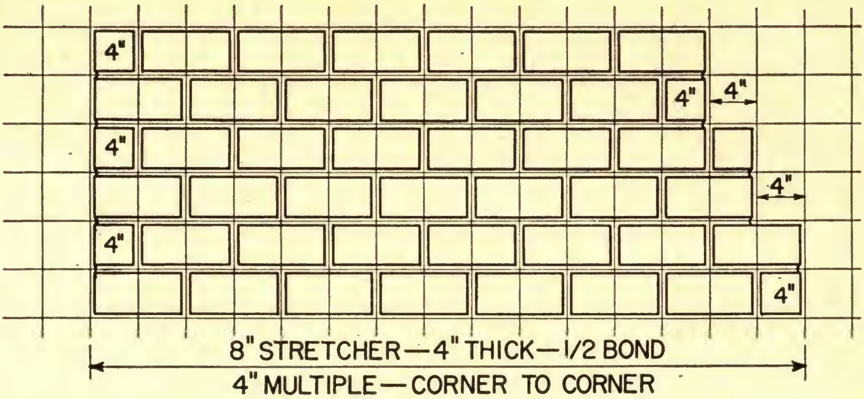


FIG. 2-15

Supplementary units required for 4-in. wall length flexibility—8-in. stretchers

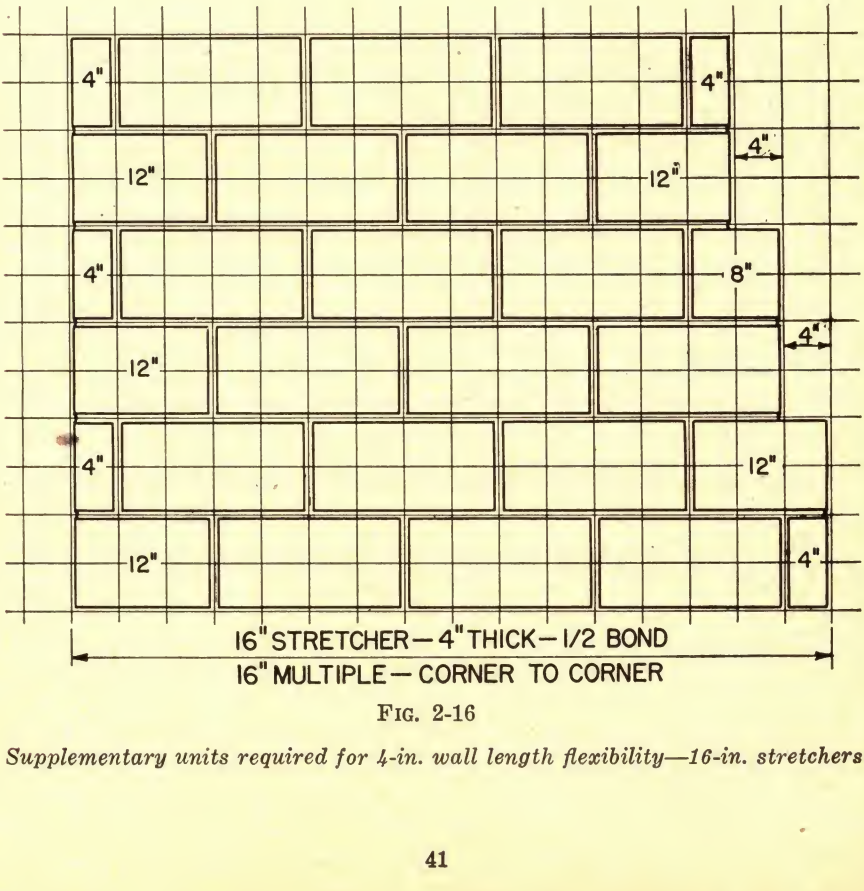


FIG. 2-16

Supplementary units required for 4-in. wall length flexibility—16-in. stretchers

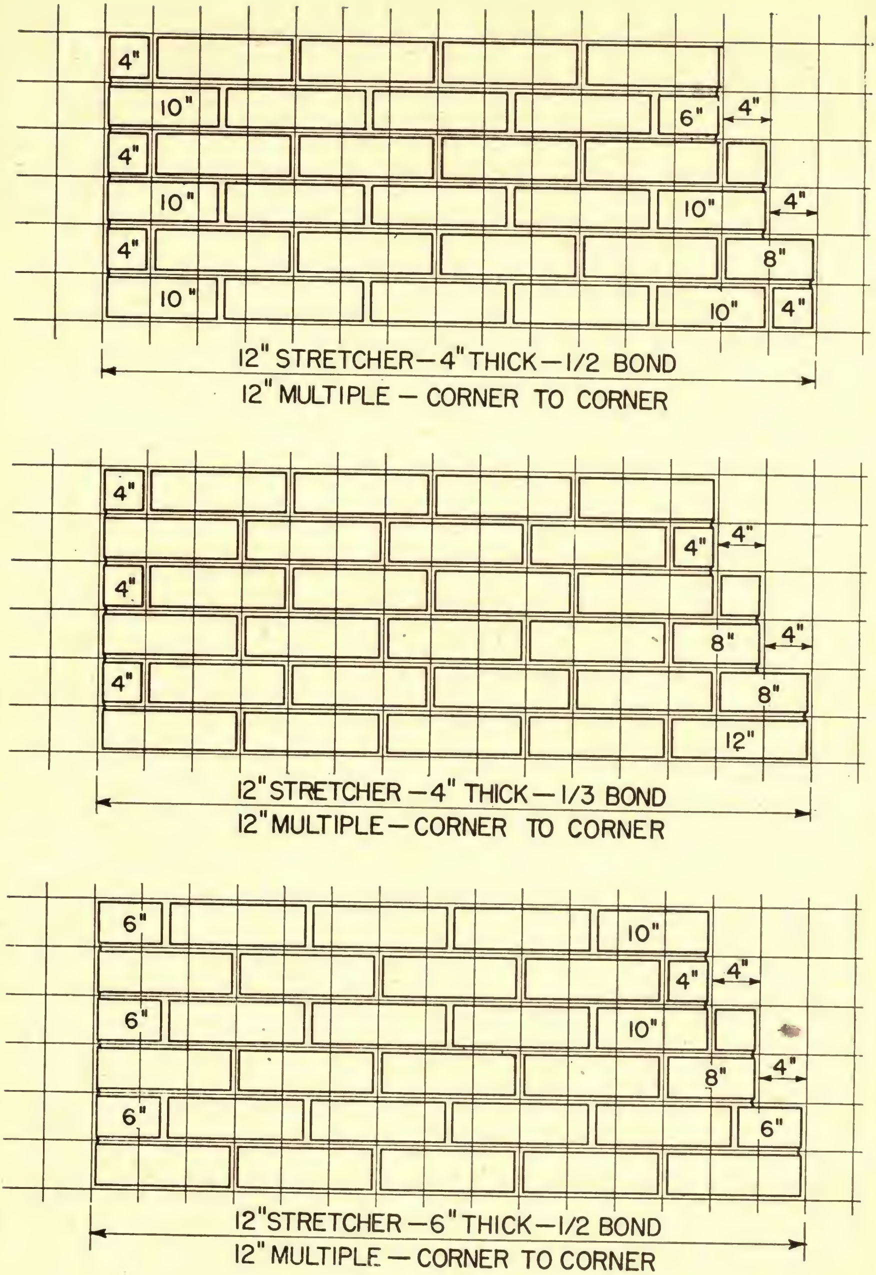


Fig. 2-17

Supplementary units required for 4-in. wall length flexibility—12-in. stretchers

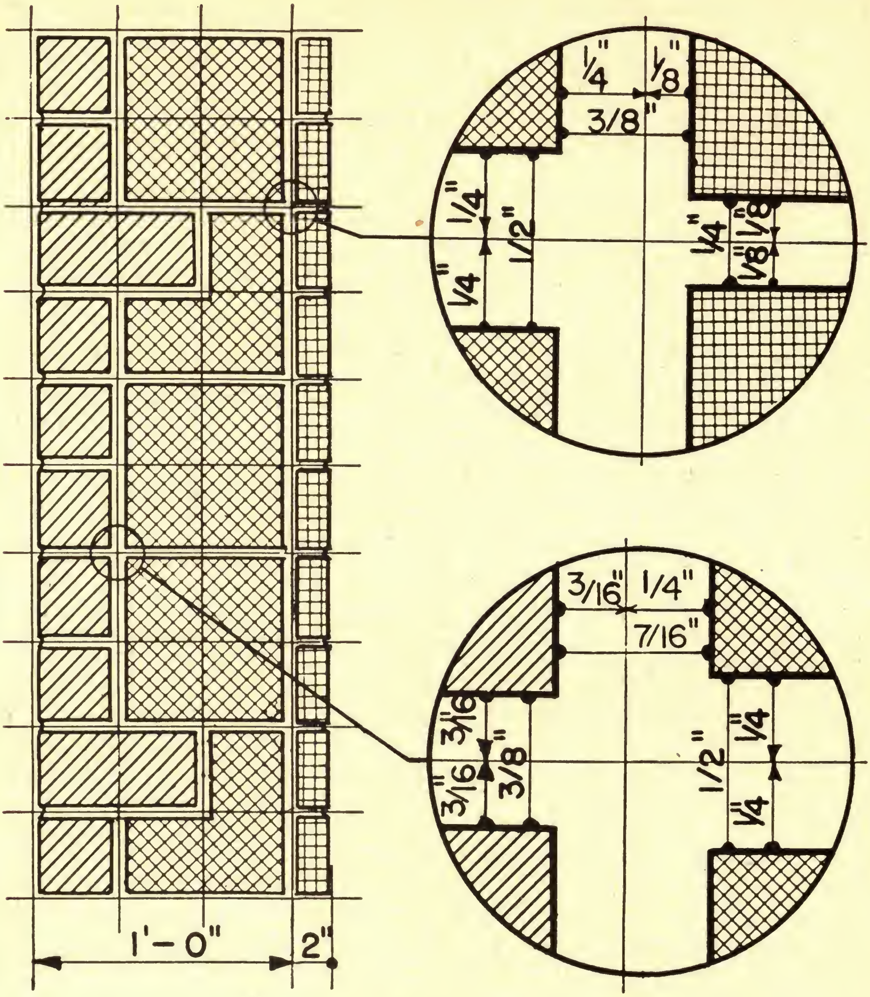


FIG. 2-18

Coordination of different masonry products

208. BUILDING LAYOUT

In applying modular coordination to building layout the architect starts his work with preliminary studies by the methods customarily employed. Many architects have found it convenient to use a large grid or module for preliminary planning and this practice in no way interferes with the later development of modular details, provided the planning module is a multiple of 4 in. Modular coordination is chiefly concerned with the preparation of working drawings after the preliminary plans have been approved.

The booklet "The Modular Method in Dwelling Design" published by the Housing and Home Finance Agency is the second publication of this agency

in a series to be issued under the Housing Act of 1948 as amended and as indicated in the foreword was "prepared, in the interest of lower cost housing, to aid in applying the principles of modular coordination to building plans and details."

This booklet is available from the Superintendent of Documents, Government Printing Office, Washington 25, D. C., and is a valuable reference on modular design.

The following Figs. 2-19 to 2-25, inclusive, with the accompanying descriptions are reproduced from HHFA publication "The Modular Method in Dwelling Design," and illustrate the method of developing modular detail for a three-story walk-up apartment building.

This booklet states: "Before proceeding with working drawings further decisions are made with respect to construction details. These decisions—based upon building code requirements, engineering analysis and personal experience—permit detailing of significant controlling parts of the structure. This procedure is common practice and not peculiar to the use of modular coordination.

"Examination of the preliminary lay-out (Fig. 2-19) makes it apparent that there are four controlling parts in plan and seven in elevation that must be detailed. These typical details establish important relationships between different materials used in the structure.

"For convenience—there is no rule—the controlling parts are identified by means of letters or numbers, or both. In the example building, an exterior corner is selected to show how masonry units are bonded. It is arbitrarily identified as W/1. For similar reasons a reentrant corner of the exterior wall is selected and identified as W/2. Other details are identified in the plan as W/3 and W/4.

"On the elevation it is desirable to establish the relationship between the walls and foundation walls and footing so that a plan of the substructure can be prepared. A section at and below the first floor is selected for detailing and assigned the symbol WF/1. Sections at the second floor and roof are also determined to be essential and are identified as WF/2 and WR/1.

"Typical details to show how window heads, jambs and sills are constructed and related to the masonry are required. The controlling parts are selected and identified for convenience as A, B, C, and C_1.

"Detailing of the controlling parts of the structure can now proceed, bearing in mind the outline specifications and other information that has been developed. If modular details meeting the desired conditions are available they may be traced or otherwise incorporated in the working drawings. For the purpose of illustration it is assumed that modular details are not available, but must be developed for this particular building.

"The exterior corner of the building, identified as W/1 (Fig. 2-19), is the first modular detail to be drawn. It is both convenient and desirable to study the bonding of the masonry as far as the window opening (Fig. 2-20). The modular masonry units to be used establish the brick mortar joints as ½ in. and the joints of the concrete back-up unit as ⅜ in.

"STEP 1. Grid lines are drawn 4" apart in both directions or commercially available grid paper may be used.

"STEP 2. At the upper-left corner of the grid the brick facing (A) is located one-half mortar joint (¼ in.) inside the grid in both directions.

"STEP 3. The nominal dimension of the window jamb from the corner is scaled on the lay-out drawing (Fig. 2-19) as 2 ft. 4 in. or 7 modules. The window jamb is located on the grid and the brick jamb is drawn one-half mortar joint to the left of the grid line.

"STEP 4. The exterior face of the side wall is continued from the corner (A), the face of the wall being one-half mortar joint from the grid line.

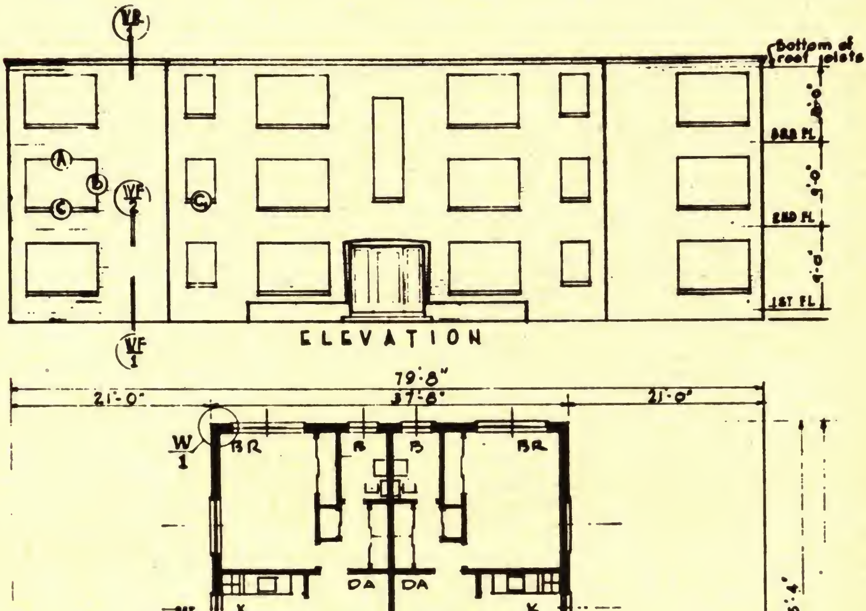


FIG. 2-19

Architect's typical preliminary layout

"STEP 5. Since the masonry wall has a nominal dimension of 12 in., the inside face of the wall is located one-half mortar joint (3/16 in. for concrete back-up) inside the grid line of the third module both ways and lines (B) are drawn.

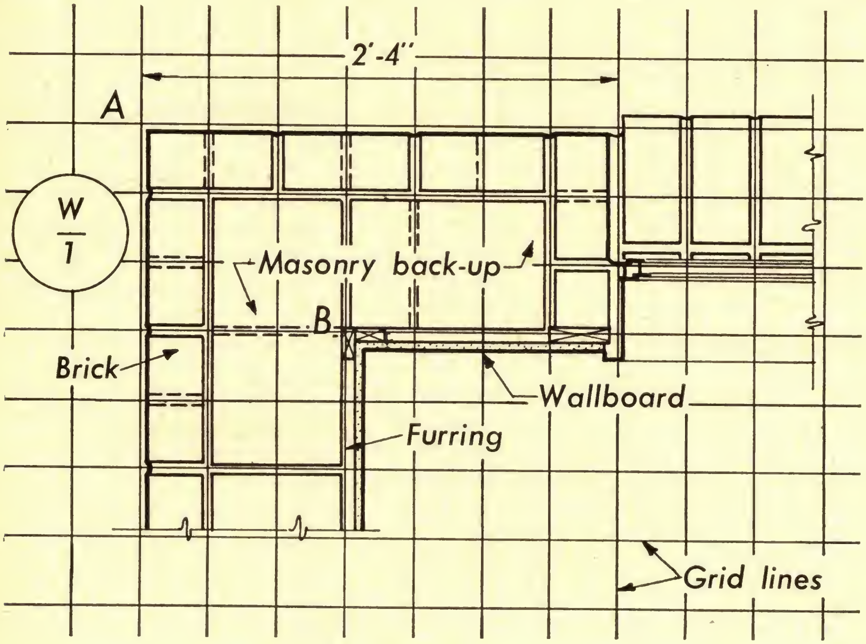


Fig. 2-20

Modular detail of exterior corner (W/1)

"STEP 6. The masonry detail is completed showing jointing of brick and back-up concrete units using dotted lines for alternate course locations. Both units are related to the grid lines, the joints between dissimilar units being the average of the joints, used with each.

"STEP 7. Furring—easily spaced 16 in. o. c. by counting grid lines—and the wallboard are added using the usual indications. The window and its location is shown in a later detail.

Details W/2, W/3 and W/4, Figs. 2-21 and 2-22, are developed in a similar manner. The step by step procedure for developing vertical wall sections is described as follows:

"Twelve inches has been determined as the nominal thickness of the first story and foundation walls. The basement and first floor concrete slabs are 4 in. To meet load requirements 12 in. x 24 in. concrete footings will be used. From this information WF/1 (Fig. 2-23) can be started.

"STEP 1. As in previous details the 4 in. grid lines are drawn.

"STEP 2. The nominal floor line of the basement is established on a grid line. The actual floor line for masonry construction is drawn ⅛ in. below the

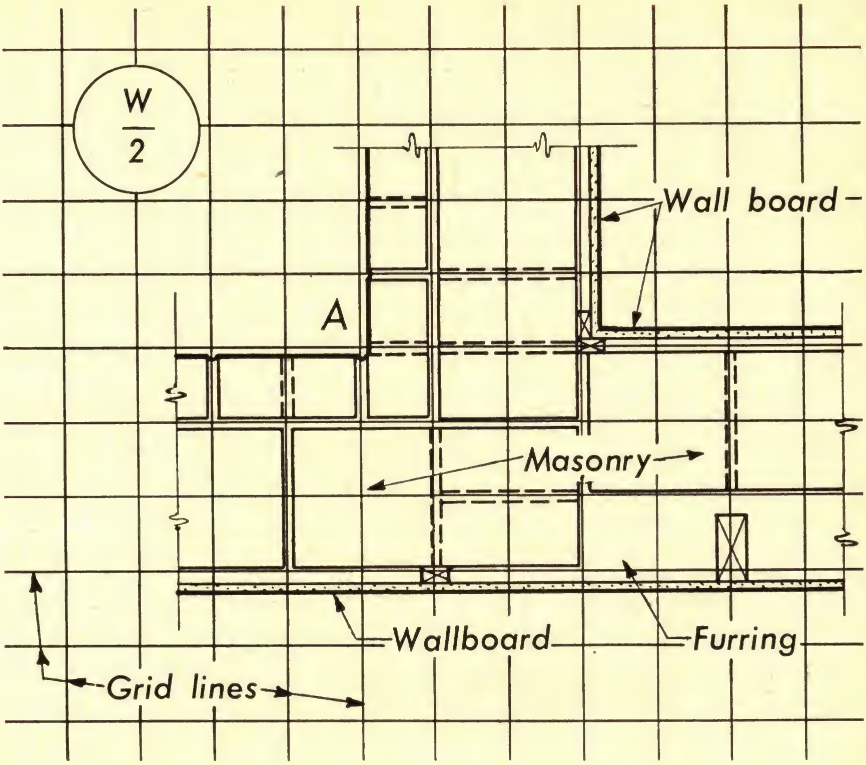


FIG. 2-21

Modular detail of exterior reentrant corner (W/2)

grid line. (For practical purposes the ⅛ in. may be disregarded since construction generally does not permit this degree of accuracy.)

"The top of the footing (A) is established one-half mortar joint (3/16 in.) below a grid line. A vertical grid line is selected as the nominal outside face of the wall. Nominal width of the wall is 3 modules wide.

"STEP 3. Modular size concrete blocks will be used having a nominal height of 8 in. Block courses are indicated by drawing the top and bottom surfaces of the blocks one-half mortar joint (3/16 in.) above and below grid lines as at (B). Both faces of the foundation wall are drawn one-half mortar joint inside the grid lines.

"STEP 4. The preliminary lay-out of the elevation centered on the foundation wall and drawn 3 modules (12 in.) high.

"STEP 5. The preliminary lay-out of the elevation established the first floor as 9 ft. 0 in. above the basement floor. Since the actual floor line is ⅛ in. below a grid line and an allowance of ⅛ in. is made for asphalt tile, the top of the concrete floor slab is drawn ¼ in. below the grid line to which it is referenced. The nominal floor, or grid line, centers on a masonry joint of the wall.

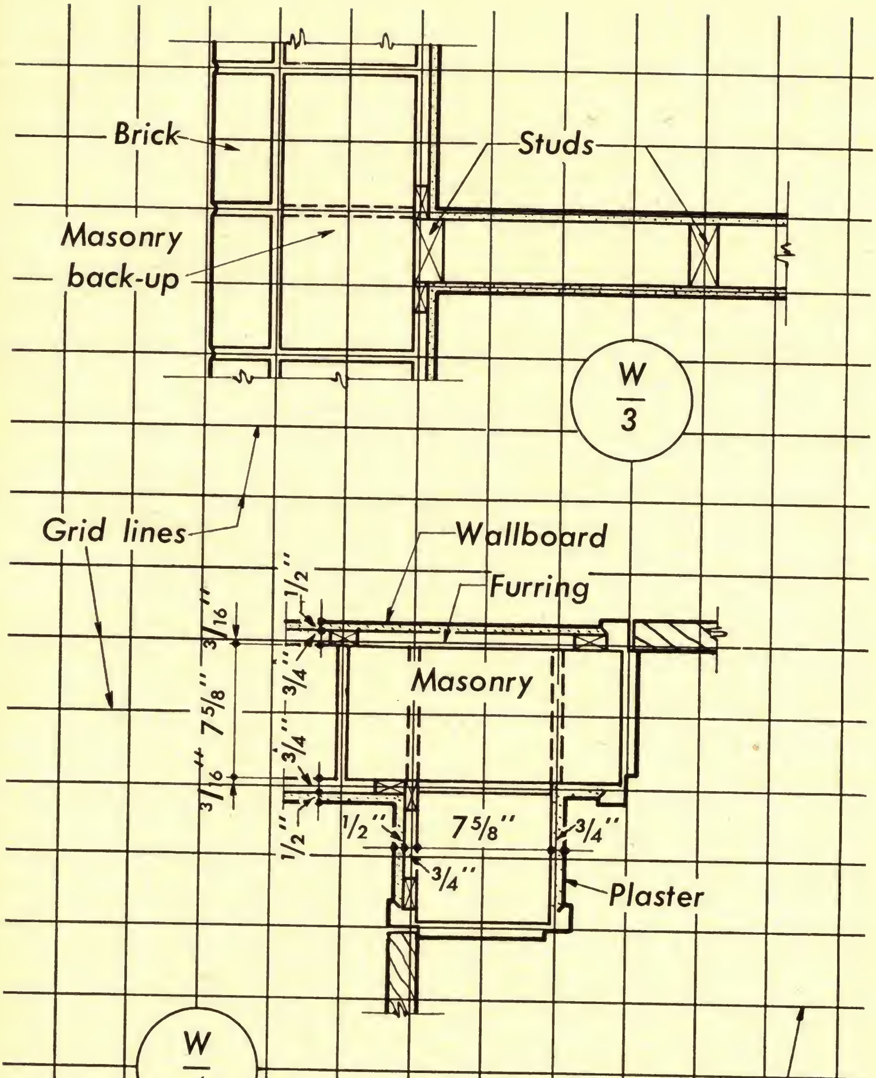


FIG. 2-22

Modular details of intersection of frame partition with exterior masonry wall (W/3) and intersection of masonry bearing walls and door jamb assemblies (W/4)

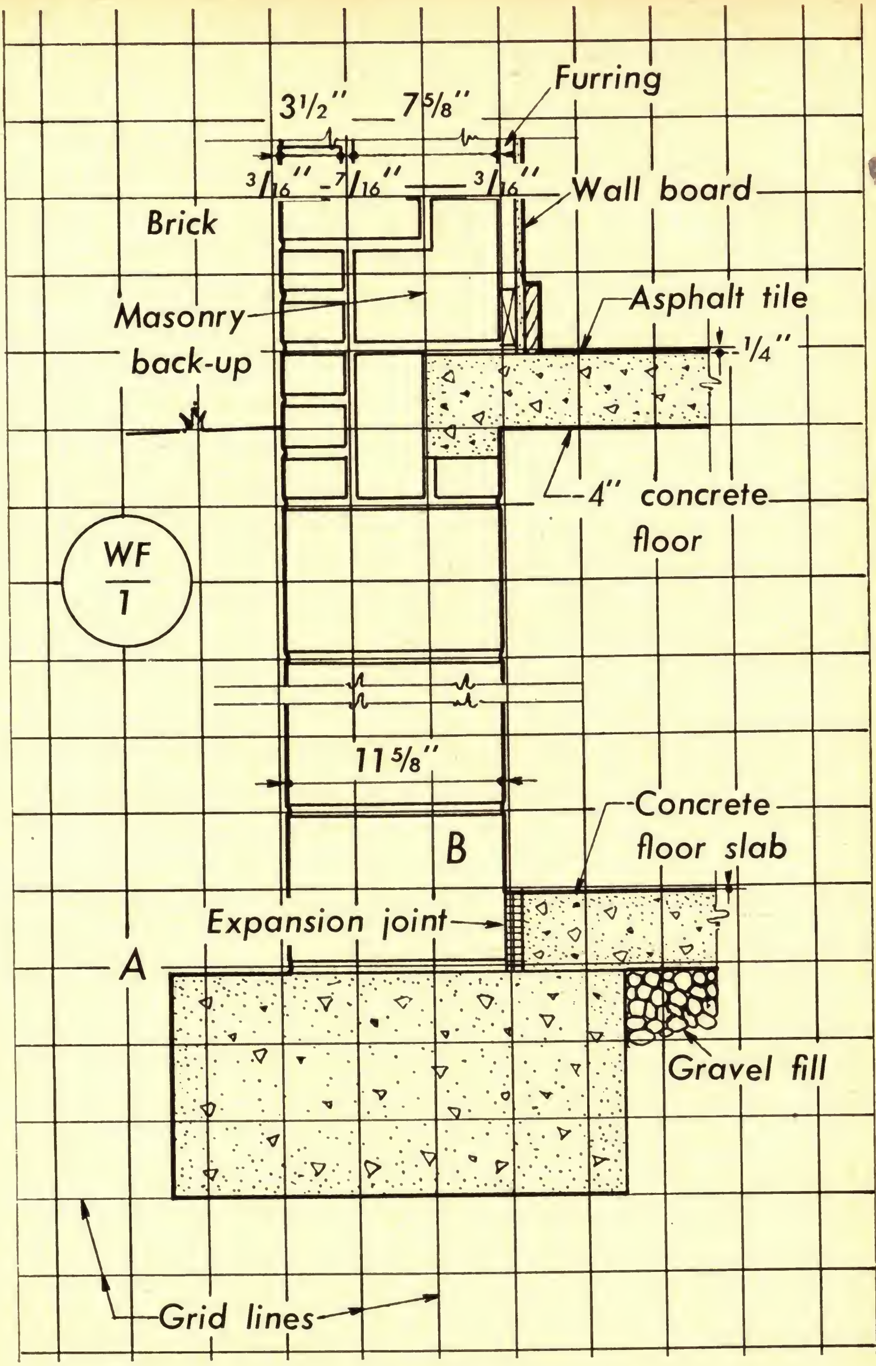


FIG. 2-23

Modular detail of footing, foundation wall and the position of the basement and first floor slabs with respect to the grid (WF/1)

"STEP 6. Beginning with the masonry joint established as the nominal floor line, vertical bonding of masonry units above the foundation is established in detail WF/1 in a similar way to that of detail W/1.

"In this example modular bricks that lay up three courses in 8 in., including ½ in. mortar joints, are used, bonded every sixth course with the concrete back-up units. Details WF/1 is completed by showing the relationship between the wall units, floor slab and foundations, and adding the furring and wallboard.

"Before starting detail WF/2 (Fig. 2-24) it is found that 10 in. joists will be used. Total depth of the construction including the ceiling, subfloor, and wood-finish floor is approximately 12 in. The desired ceiling height is 8 ft. 0 in., so that the floor-to-floor dimension is 9 ft. 0 in.

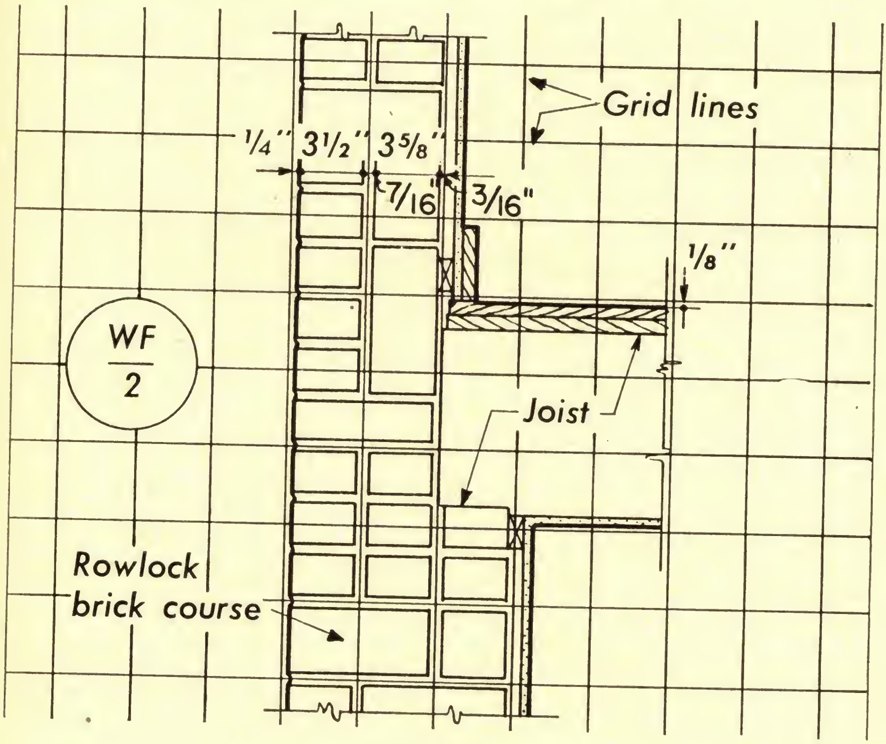


FIG. 2-24

Modular detail of intersection of second floor joists with exterior masonry wall (WF/2)

"Since the 9 ft. 0 in. ceiling height results in an odd number (27) of 4 in. modules the nominal (grid) floor line will center on a brick when brick are laid three courses to 8 in. This position of the floor line would cause window head heights to vary by one-half brick course in alternated stories when steel lintels are inserted in brick joints. This relationship between the brick coursing and the floor line would also require the use of half-brick fillers at joist bearings.

"Variation of window head heights and the need for fillers under joists can be overcome by using a rowlock brick course above the window heads. This change in the masonry coursing results in the floor line centering on a masonry joint.

"Had the floor height been an even number of modules, the nominal floor line would have centered on a masonry joint. No variation would then occur in window heads, nor would fillers be needed for joist bearing.

"Detail WF/2 is completed by placing the top of the wood-finish floor ⅛ in. below the grid line; showing the bonding of the masonry units; and indicating the interior finish surfaces.

"In studying the controlling detail of the wall and roof (Fig. 2-25), the nominal course of masonry nearest the desired 8 ft. 0 in. ceiling height is selected for bearing without notching the joists. A rowlock brick course is used to obtain the desired relationship between the masonry and roof construction. In other respects development of the detail follows the procedure previously described."

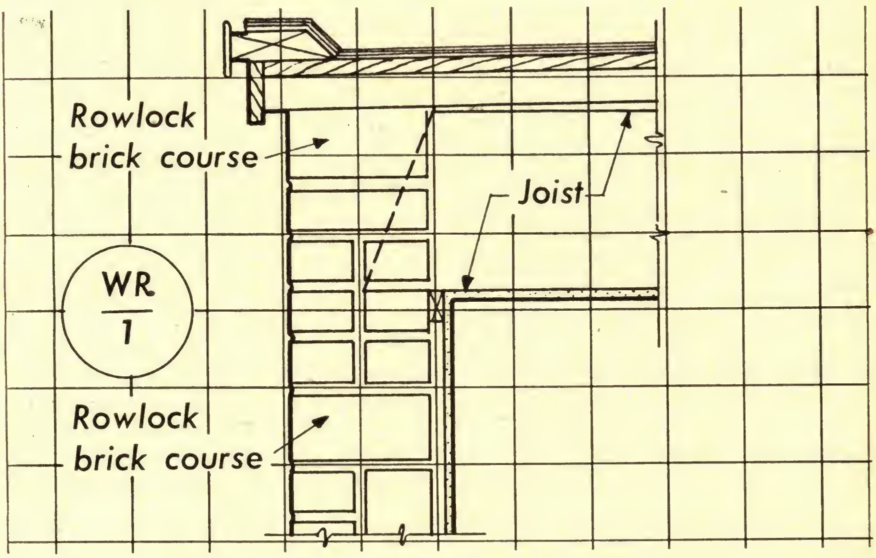


FIG. 2-25

Modular detail of exterior wall and roof (WR/1)

209. MODULAR SMALL HOUSE LAYOUT

Fig. 2-26 is a rendering of a masonry house designed for the Structural Clay Products Institute to illustrate the application of modular coordination to the layout of house plans.

In selecting modular unit sizes for the masonry house shown in Fig. 2-26, it was decided that the brick and tile should conform closely to generally available non-modular sizes. For this reason, nominal 2⅔-in. brick (three courses in 8 in.) and the nominal 8-in. structural tile were selected for the outer and inner cavity wall wythes as shown in Fig. 2-27.

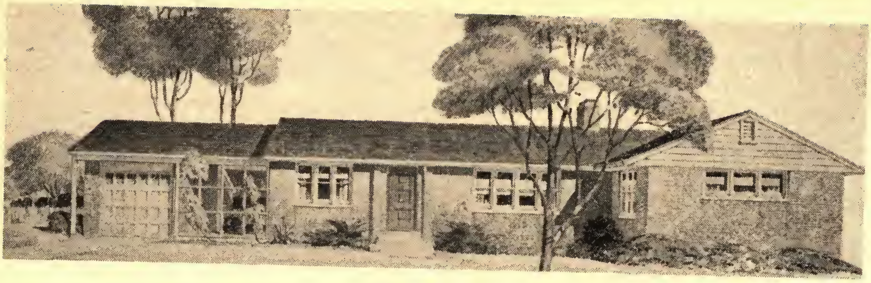


FIG. 2-26

Perspective of the house

Fig. 2-28 shows the wall section. Ordinarily grid lines are not used for small scale sections but they were added to Fig. 2-28 to show the grid position of walls and floors.

It will be noted that the grid line to which the finished floor is referenced passes through the center of the brick in the wall. This grid location was necessary because the beds of the sills of the three types of windows used were 1 ft. 8 in., 2 ft. 4 in., and 4 ft. 4 in. above the finished floor. These dimensions are all odd multiples of 4 in., and consequently to bring the sill bed at a horizontal mortar joint the reference grid line (at finished floor) must pass through the center of the brick when 3 courses to 8 in. modular brick are used. The sill used has a nominal height of 4 in. and may be either a rolok brick sill or cast stone sill.

The over-all nominal 10-in. wall thickness presented an initial problem to determine which of the two wythes should be centered on a grid line. Some original studies with brick veneer construction suggested that the brick wythe be centered. In that case, however, all brick end joints occur at the mid-grid lines. By centering the inner tile wythe on the grid, both the tile and brick could be placed in a typical layout arrangement as related to end-joint position. In addition, the 8-in. foundation wall is placed between two grid lines rather than centered on a mid-grid line. With 12-in. length foundation tile, this would not provide any particular problem since the end joints in alternate courses are ordinarily at the mid-grid lines and a similar condition would exist.

An examination of the floor plans, Fig. 2-29 and 2-30, will reveal that exterior dimensions are all multiples of 4 in. Interior dimensions are multiples of 4 in. or multiples of 4 in. plus 2 in. These are nominal dimensions between two nominal faces. On plans, sections, elevations, etc., where no grid lines are shown, the conventional arrow is used on the dimension line to indicate coincidence with a grid line. At all other locations, small dots are used instead of the arrow symbol.

Large scale details are used to reference the nominal dimensions to the grid lines. These are "modular details" and are referenced to the grid by dimensions that give exact locations relative to grid lines.

Fig. 2-31 and 2-32 illustrate typical modular details for the basement and first floor windows. The complete plans also include separate installation details for typical wall and floor sections showing the sizes and positions of the actual units with respect to the grid lines. The actual masonry surfaces are set back the distance of one-half the standard mortar joint from the nominal surface.

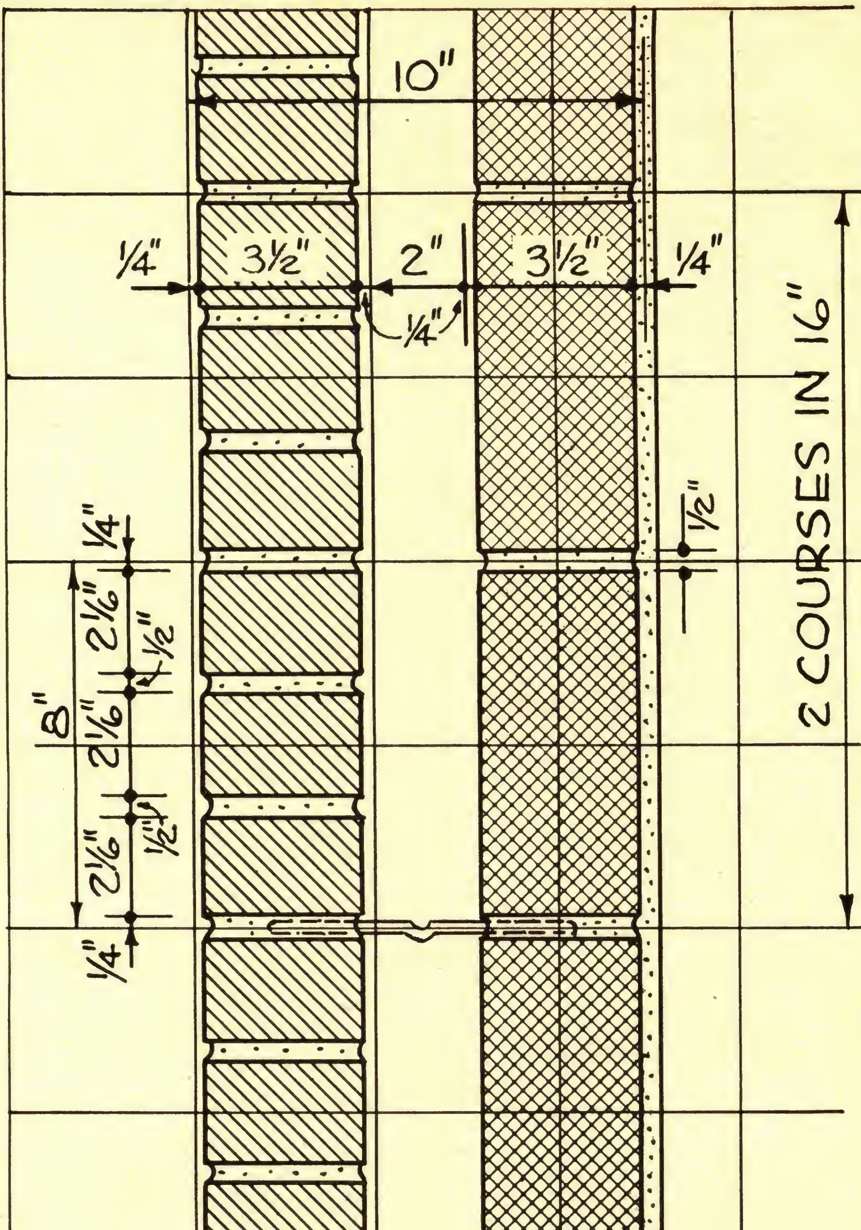


FIG. 2-27

Modular detail of 10-in. cavity wall

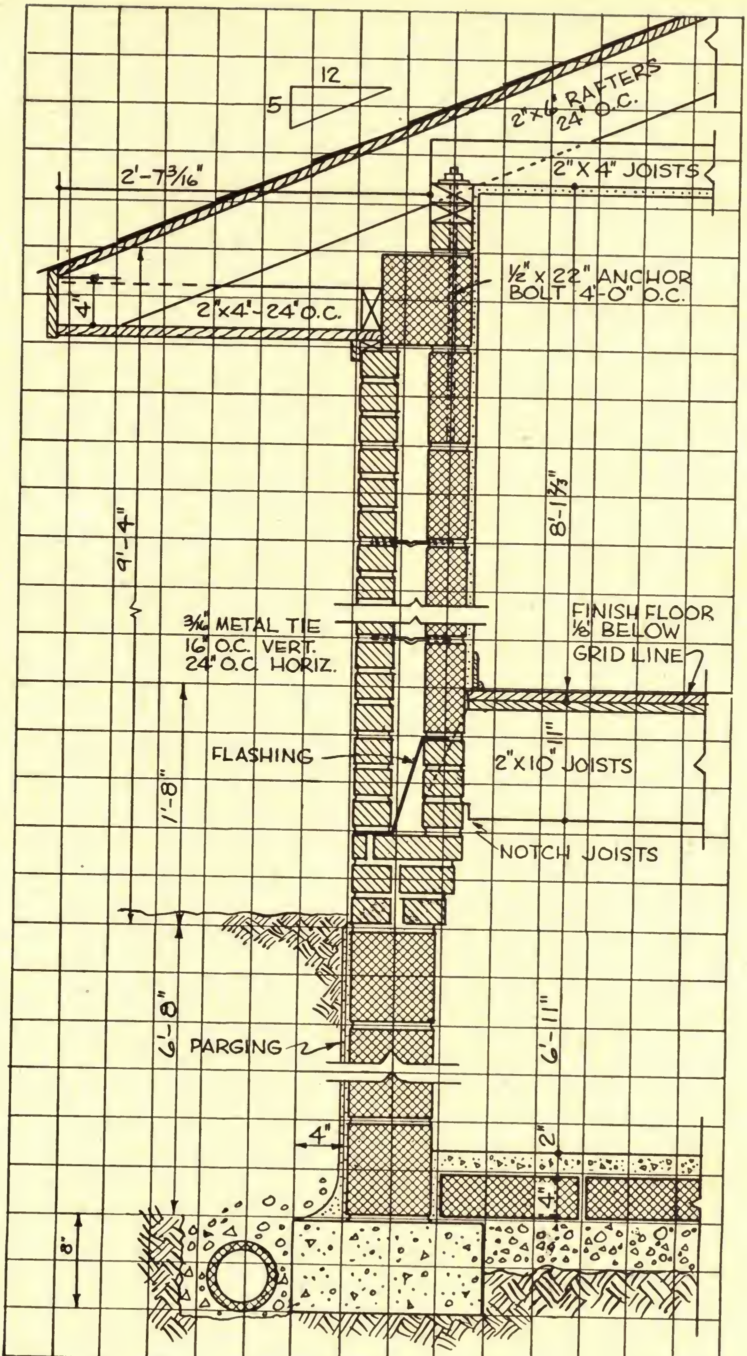


Fig. 2-28
Typical wall section

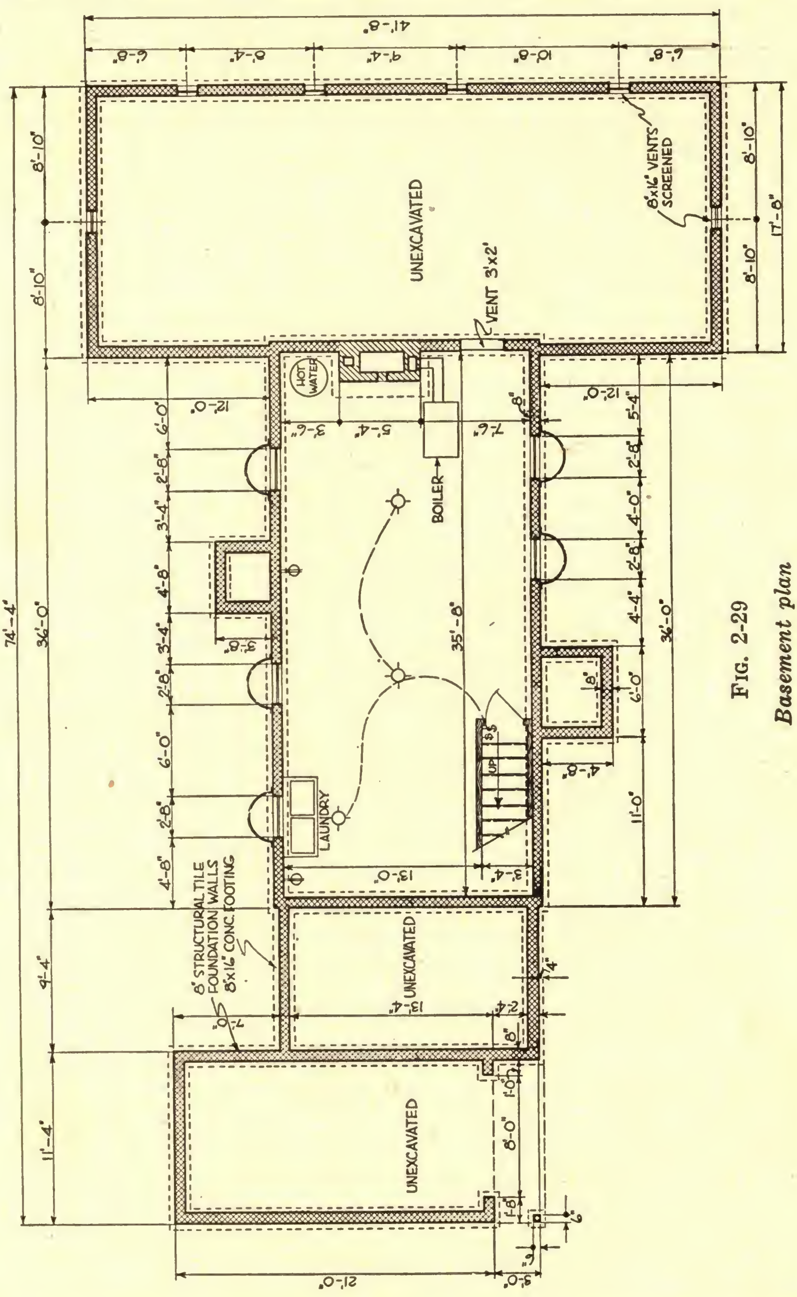


FIG. 2-29

Basement plan

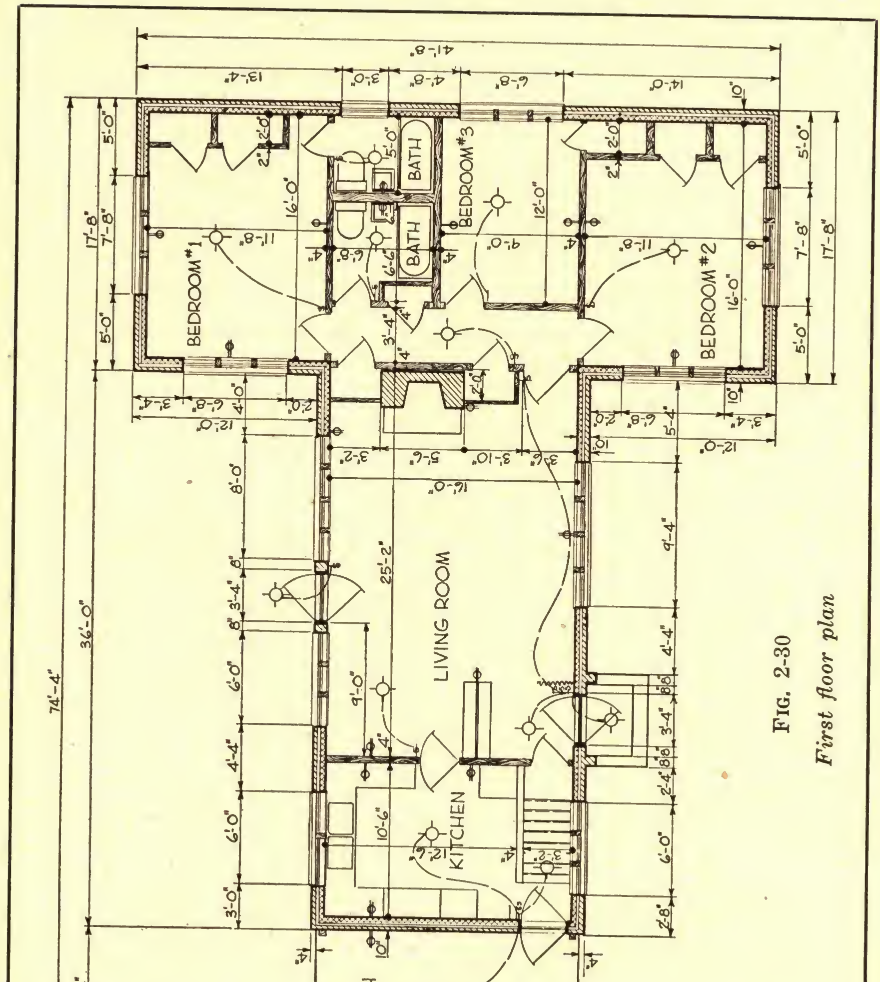


FIG. 2-30
First floor plan

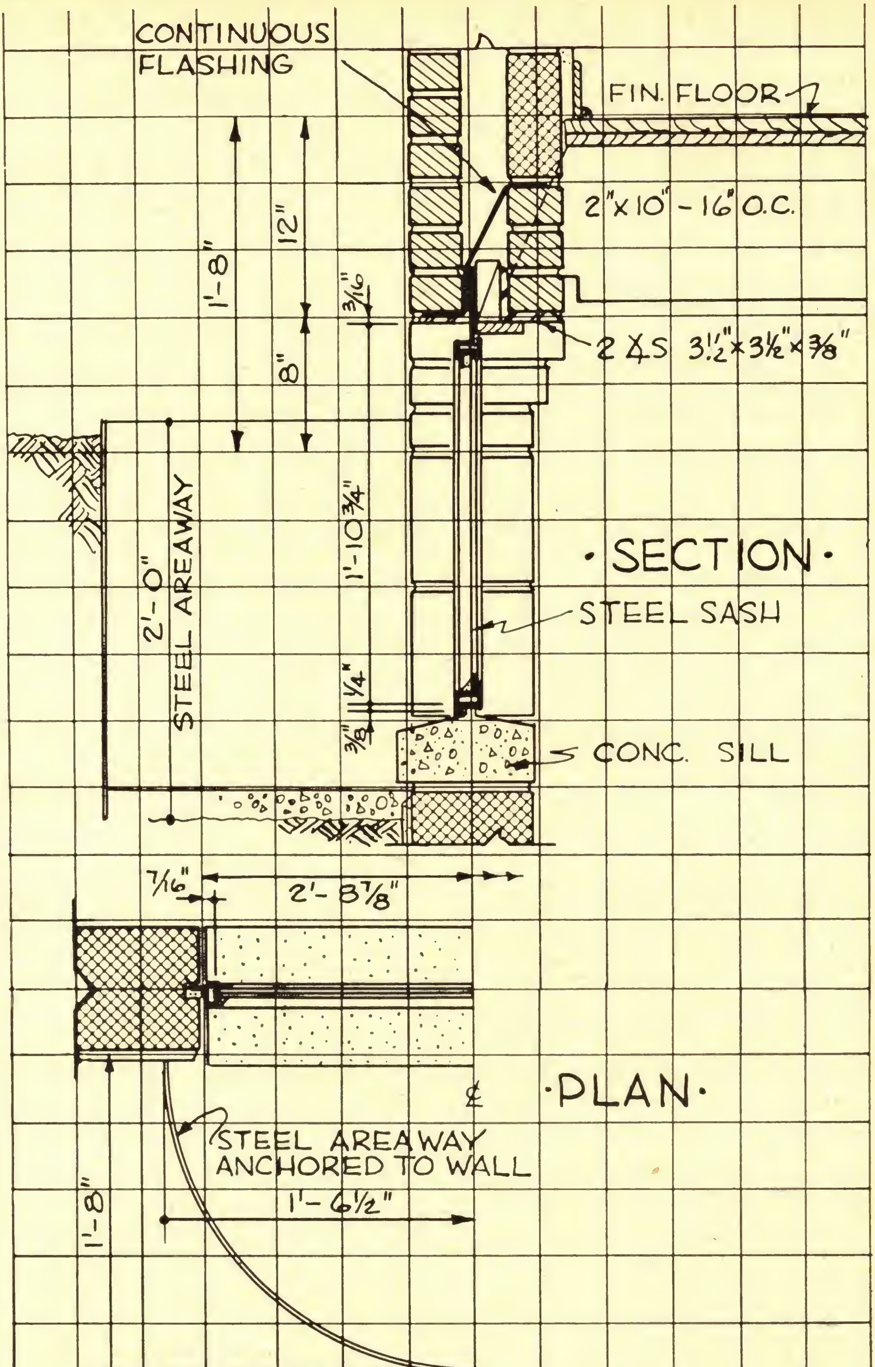


Fig. 2-31
Modular detail of basement window

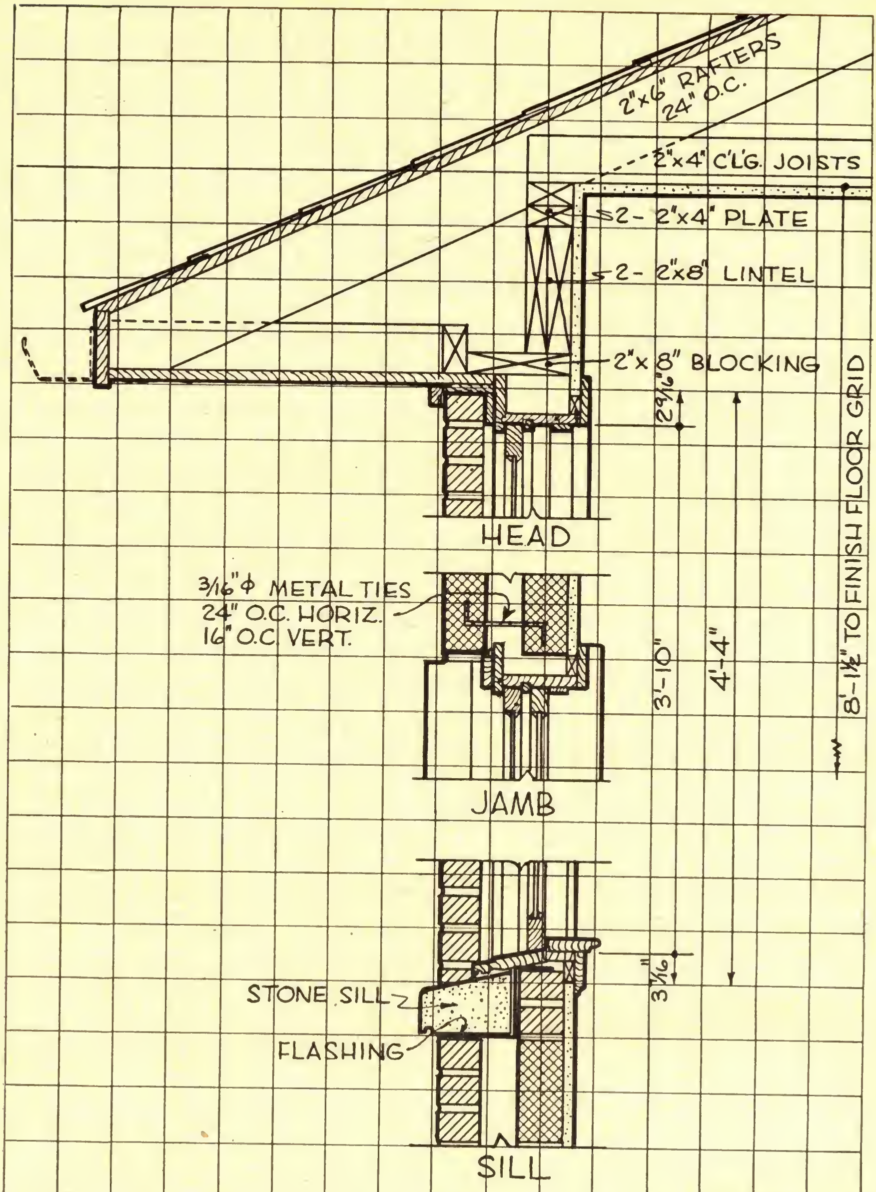


FIG. 2-32

Modular detail of typical first floor window

CHAPTER 3

CLASSIFICATION, SIZE, COLOR AND TEXTURE

301. GENERAL DEFINITIONS

The following definitions are of terms included in the recognized terminology of the structural clay products industry.

RAW MATERIALS

Clay. An earthy or stony mineral aggregate consisting essentially of hydrous silicates of alumina, plastic when sufficiently pulverized and wetted, rigid when dry, and vitreous when fired to a sufficiently high temperature.

Surface Clay. An unconsolidated, unstratified clay, occurring on the surface.

Shale. A thinly stratified, consolidated, sedimentary clay with well marked cleavage parallel to the bedding.

Fire Clay. A sedimentary clay of low flux content. (Fire clay is usually associated with coal measures.)

PRODUCTS

Solid Masonry Unit. A unit whose net cross-sectional area in every plane parallel to the bearing surface is 75 per cent or more of its gross cross-sectional area measured in the same plane.

Brick are included in this classification and most solid clay masonry units produced comercially are marketed as a type of brick, such as Roman brick (2x4x12 in.), Norman brick (2⅔x4x12 in.), and double brick (5⅓x4x8 in.), (dimensions nominal: height x thickness x length).

In this book, when the term brick is used, it should be understood to mean brick or solid clay masonry unit.

Hollow Masonry Unit. A masonry unit whose net cross-sectional area in any plane parallel to the bearing surface is less than 75 per cent of its gross cross-sectional area measured in the same plane.

Structural clay tile are included in this classification; however, hollow clay masonry units include many clay products whose net areas are less than 75 per cent of the gross area, but are greater than the minimum net areas permitted by specifications for structural clay tile.

In this book, when the term structural clay tile is used, it should be understood to mean structural clay tile or hollow clay masonry units.

Building or Structural Unit. A unit, the specifications for which include measures of durability, strength and other structural properties, but not requirements affecting appearance.

This classification includes Building Brick and Structural Clay Tile.

Structural Facing Unit. A structural or building unit designed for use where one or more faces will be exposed in the finished wall and for which specifications include requirements on color, finish and other properties affecting appearance.

This classification includes Facing Brick and Structural Clay Facing Tile.

STRUCTURAL CLAY TILE

Load-Bearing Tile. Tile for use in masonry construction designed to carry superimposed loads.

Non-Load-Bearing Tile. Tile for use in masonry construction carrying no superimposed loads.

Partition Tile. Tile for use in building interior partitions, subdividing areas into rooms, or similar construction, and carrying no superimposed loads.

Fireproofing Tile. Tile for use as protection for structural members against fire.

Furring Tile. Tile for lining the inside of walls and carrying no superimposed loads.

Floor Tile. Tile for use as structural units in floor and roof construction.

Header Tile. Tile designed to provide recesses for header units in masonry faced walls.

Side-Construction Tile. Tile designed to receive its principal stress at right angle to the axes of the cells.

End-Construction Tile. Tile designed to receive its principal stress parallel to the axes of the cells.

SURFACE FEATURES

Smooth Finish. A surface not altered or marked in manufacture but left as a plane surface as formed by the die.

Scored Finish. A surface grooved as it comes from the die to give increased bond for mortar, plaster or stucco.

Combed Finish. A surface altered by more or less parallel scratches or scarfs in manufacture to produce a desired texture or to give increased bond for mortar, plaster or stucco.

Roughened Finish. A surface entirely broken by mechanical means, such as wire cutting or wire brushing to produce a desired texture or to give increased bond for mortar, plaster or stucco.

Ceramic Glaze. A coating compounded of metallic oxides, chemicals and clays, thoroughly ground together and sprayed upon a previously formed body either before or after drying. Units are then burned at high temperatures, fusing the glaze to the body and making them inseparable.

Ceramic Color Glaze. A surface covered by an inseparable fire-bonded colored ceramic glaze of satin or gloss finish.

Ceramic Clear Glaze. A surface covered by an inseparable fire-bonded translucent or tinted ceramic glaze of lustrous finish.

Non-Lustrous Glaze. A surface covered by an inseparable fire-bonded ceramic glaze of non-lustrous finish.

Salt Glaze. A surface having a lustrous glaze finish from the thermochemical reaction of the silicates of the clay body with vapors of salts or chemicals.

Natural Finish. A surface, unglazed or uncoated, burned to the natural color of the material used in forming the body.

302. TYPES OF BRICK

(a) **Building Brick.** The requirements for building brick are included in ASTM Specification C62—which covers 3 grades of brick based on resistance to weathering and are described as follows:

Grade SW. Brick intended for use where a high degree of resistance to frost action is desired and the exposure is such that the brick may be frozen when permeated with water.

Note: As a typical example, brick used for foundation courses and retaining walls in portions of the United States subject to frost action should conform to this grade. Compliance with this grade is also recommended where a high and uniform degree of resistance to distintegration by weathering is desired.

Grade MW. Brick intended for use where exposed to temperatures below freezing but unlikely to be permeated with water or where a moderate and somewhat non-uniform degree of resistance to frost action is permissible.

Note: As a typical example, brick used in the face of a wall above grade should conform to this grade. Such exposure is not likely to result in permeation of a brick by water if horizontal surfaces are protected.

Grade NW. Brick intended for use as backup or interior masonry, or if exposed, for use where no frost action occurs; or if frost action occurs where the average annual precipitation is less than 20 in.

When water is in contact with a surface of a dry unit, the tendency is for the water to enter the unit by capillary suction. If there is enough water and the time of contact is sufficiently long, the water will strike through from face to face, giving a degree of saturation equaling or exceeding that resulting from a 24-hr. submersion in water at room temperature. This wetting through from face to face describes the condition of being "permeated," referred to in the ASTM specification.

The physical requirements for each grade, included in ASTM Specification C62—, are given in Table 3-1.

TABLE 3-1

PHYSICAL REQUIREMENTS

Designation	Minimum Compressive Strength (brick flatwise), psi, gross area		Maximum Water Absorption by 5-hr. Boiling per cent		Maximum Saturation Coefficient ①	
	Average of 5 brick	Individual	Average of 5 brick	Individual	Average of 5 brick	Individual
Grade SW	3000	2500	17.0	20.0	0.78	0.80
Grade MW	2500	2200	22.0	25.0	0.88	0.90
Grade NW	1500	1250	No limit	No limit	No limit	No limit

① The saturation coefficient is the ratio of absorption by 24-hr. submersion in cold water to that after 5-hr. submersion in boiling water.

(b) Facing Brick. Requirements for facing brick are included in ASTM Specification C216—. This specification covers 2 grades of brick based on resistance to weathering, the physical requirements and recommended uses for which are the same as for building brick, grades SW and MW, and 3 types based upon factors affecting the appearance of the finished wall. These types are described in the specification as follows:

Type FBX. Brick for general use in exposed exterior and interior masonry walls and partitions and for use where a high degree of mechanical perfection, narrow color range, and minimum permissible variation in size are desired.

Type FBS. Brick suitable for general use in exposed exterior and interior masonry walls and partitions where wide color ranges are desired and where a greater variation in size is permitted or desired than is specified for type FBX.

Type FBA. Brick manufactured and selected to produce characteristic architectural effects resulting from non-uniformity in size, color, and texture of the individual units.

(c) Glazed Facing Brick. The requirements for Glazed Facing brick are included in ASTM Specification C126— and in the specifications of the Facing Tile Institute. In addition to minimum compressive strength and maximum absorption requirements, these specifications include tests of finish (imperviousness, chemical and crazing) and limitations on distortion and variations in dimensions.

303. TYPES OF STRUCTURAL CLAY TILE

Structural Clay Tile may be classified under the following types: Structural Clay Load-Bearing Wall Tile, Structural Clay Non-Load-Bearing Tile (partition, furring and fireproofing), Structural Clay Floor Tile, Structural Clay Facing Tile, and Structural Glazed Facing Tile. Structural Clay Floor Tile are not covered in this book.

(a) Structural Clay Load-Bearing Wall Tile. This classification includes:

1. Wall tile which are designed for use in the construction of exposed or faced load-bearing walls. Facing may consist of stucco, plaster or other materials, but the tile is designed to carry the entire superimposed load which may include the weight of the facing materials.

2. Backup tile which are designed for use in the construction of load-bearing and non-load-bearing combination walls of brick or other masonry units and tile, in which the facing units are bonded to the backing by headers or masonry bonding units, and the superimposed load is supported by both the facing and backing. Backup tile include header tile and stretcher units.

Requirements for structural clay load-bearing wall tile are included in ASTM Specification C34—which covers 2 grades based upon resistance to weathering. These grades are described in the specifications as follows:

Grade LBX. Suitable for general use in masonry construction and adapted for use in masonry exposed to weathering, provided they are burned to the normal maturity of the clay. They may also be considered suitable for the direct application of stucco.

Grade LB. Suitable for general use in masonry where not exposed to frost action, or for use in exposed masonry where protected with a facing of 3 in. or more of stone, brick, terra cotta, or other masonry.

The physical requirements for each grade, included in ASTM Specification C34-, are given in Table 3-2.

TABLE 3-2

PHYSICAL REQUIREMENTS

Grade	Maximum Water Absorption ① by 1-hr. Boiling, per cent		Minimum Compressive Strength (Based on Gross Area), ② psi			
			End-Construction Tile		Side-Construction Tile	
	Average of five tests	Individual	Average of five tests	Individual	Average of five tests	Individual
LBX	16	19	1400	1000	700	500
LB	25	28	1000	700	700	500

① The range in percentage absorption for tile delivered to any one job shall be not more than 12.

② Gross area of a unit shall be determined by multiplying the horizontal face dimension of the unit as placed in the wall by its thickness.

(b) Structural Clay Non-Load-Bearing Tile. This classification includes:

1. Partition tile designed for use in the construction of non-load-bearing interior partitions or for backing up non-load-bearing combination walls.
2. Furring tile used for lining the inside of walls to provide a plaster base and an air space between plaster and wall.
3. Fireproofing tile used for protecting structural members, particularly steel girders, beams and columns, against fire.

Requirements for Structural Clay Non-Load-Bearing Tile are included in ASTM Specification C56—. This specification covers one grade only and the only physical requirements are limitations on maximum absorption of 25 per cent and maximum range of absorption for one job of 12 per cent.

(c) Structural Clay Facing Tile. Requirements for Structural Clay Facing Tile are included in ASTM Specification C212—. This specification covers two classes of tile, standard and special duty, based upon the thickness of the face shells; and two types based upon factors affecting the appearance of the finished wall. These types are described as follows:

Type FTX. Smooth face tile suitable for general use in exposed exterior and interior masonry walls and partitions, and adapted for use where tile low in absorption, easily cleaned, and resistant to staining are required, and where a high degree of mechanical perfection, narrow color range, and minimum variation in face dimensions are desired.

Type FTS. Smooth or rough textured facing tile suitable for general use in exposed exterior and interior masonry walls and partitions and adapted for use where tile of moderate absorption, moderate variation in face dimensions, and medium color range may be used and where minor defects in surface finish, including small handling chips, are not objectionable.

The physical requirements for each type and class are given in Tables 3-3 and 3-4, respectively.

TABLE 3-3

MAXIMUM WATER ABSORPTION

Type	By 24-hr. Submersion in Cold Water, per cent		By 1-hr. Boiling per cent	
	Average	Individual	Average	Individual
FTX	7	9	9	11
FTS	13	16	16	19

TABLE 3-4

COMPRESSIVE STRENGTH BASED ON GROSS AREA

Class	End-Construction Tile		Side-Construction Tile	
	Minimum Average of 5 tests, psi	Individual minimum, psi	Minimum Average of 5 tests, psi	Individual minimum, psi
Standard	1400	1000	700	500
Special duty...	2500	2000	1200	1000

(d) Structural Glazed Facing Tile. Requirements for Structural Glazed Facing Tile are included in ASTM Specification C126—and in the specifications of the Facing Tile Institute. In addition to minimum compressive strength and maximum absorption requirements, these specifications include tests of finish (imperviousness, chemical and crazing) and limitations on distortion and variations in dimensions.

304. UNIT DIMENSIONS

A nominal dimension of a masonry unit is equal to the standard or specified dimension, plus the thickness of the mortar joint with which the unit is designed to be laid, as indicated in Fig. 3-1; that is, the standard length of a unit whose nominal length is 12 in. would be 11½ in. if the unit were designed to be laid with a ½ in. mortar joint, or 11⅝ in. if the unit were designed to be laid with a ⅜ in. joint.

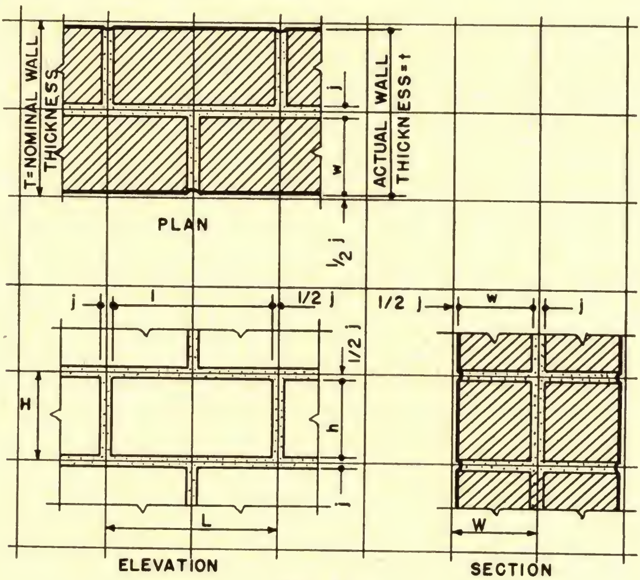


FIG. 3-1

Capital letters signify NOMINAL *Dimensions. Lower case letters signify Standard or Specified Dimension. (j) = Thickness of standard mortar joint.*

Actual unit dimensions may vary from standard or specified dimensions by not more than the permissible tolerances for variation of dimensions.

The standard joint thickness is subtracted from each of the three nominal dimensions of a masonry unit to obtain the standard or specified dimensions of the unit. The actual dimensions of a single unit may vary from the standard or specified dimensions by not more than the permissible tolerances for variation in dimensions.

In the tables which follow, all dimensions are nominal; the standard mortar joint thicknesses are determined by the type and quality of the product, particularly the permissible variation in dimensions.

In general, the mortar joint thicknesses are ¼ in. for glazed brick and tile, ⅜ in. or ½ in. for facing brick and facing tile, and ½ in. for building brick and structural tile.

305. SIZES OF BRICK

The American Standard Sizes of Clay and Concrete Modular Masonry Units, A62.3, approved in August 1946, lists modular sizes of clay and concrete masonry units. Since the adoption of this standard, additional modular sizes have been produced by the industry which can be laid economically in modular construction, but which would require excessive cutting if used in a non-modular design.

Table 3-5 lists the sizes of brick currently (1950) available; however, few manufacturers produce all of the sizes listed and it is suggested that the purchaser ascertain the sizes available in any locality before proceeding with a design.

TABLE 3-5

NOMINAL MODULAR SIZES OF BRICK ①

Thickness, in.	Face Dimension in Wall	
	Height, in.	Length, in.
4	2	12
4	2⅔	8
4	2⅔	12
4	4	8
4	4	12
4	5⅓	8
4	5⅓	12

① Nominal sizes include the thickness of the standard mortar joint for all dimensions.

306. SIZES OF STRUCTURAL CLAY TILE

Shapes and sizes shown in this section are of wall and partition tile only. The dimensions of fireproofing units are given in Chapter 10.

Modular sizes of structural wall tile are given in Tables 3-6 and 3-7. However, it should be understood that few if any manufacturers will stock all of the sizes listed.

Only the dimensions of full size units are listed in the tables; half lengths and half heights, as well as corner and jamb units, are available in most series for bonding. Wall layouts utilizing these units are illustrated in Chapter 8.

Fig. 3-2 shows typical units of the types produced most extensively. The full range of sizes listed in Tables 3-6 and 3-7 is available in most of the types shown.

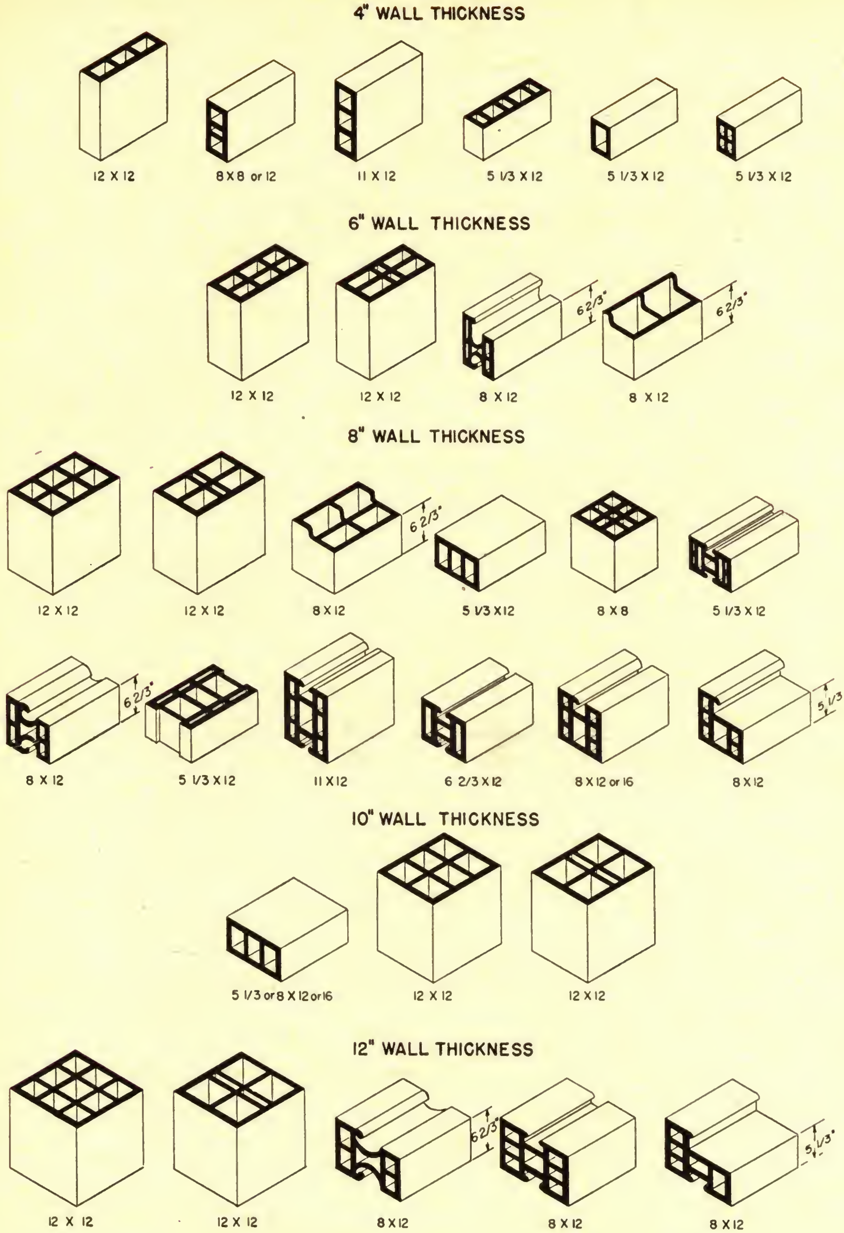


FIG. 3-2

Various standard shapes of load-bearing structural clay tile

Note: All dimensions are nominal. Face dimensions are given height by length.

TABLE 3-6

NOMINAL MODULAR SIZES OF STRUCTURAL LOAD-BEARING TILE ①

Backup Tile			Wall Tile		
Thickness, in.	Face Dimension in Wall		Thickness, in.	Face Dimension in Wall	
	Height, in.	Length, in.		Height, in.	Length, in.
4	2⅔	8 or 12	4	5⅓	12
4	5⅓	12②	4	8	8 or 12
4	8	8 or 12	4	12	12
4	10⅔	12	6	5⅓	12
6	5⅓	12	6	12	12
6	8	12②	8	5⅓	12
6	10⅔	12	8	6	12
8	5⅓	12	8	8	8, 12 or 16
8	8	8 or 12②	8	12	12
8	10⅔	12	10	8	12
			10	12	12
			12	12	12

① Nominal sizes include the thickness of the standard mortar joint for all dimensions.
② Includes header and stretcher units.

TABLE 3-7

NOMINAL MODULAR SIZES OF STRUCTURAL FACING TILE ①

Thickness, in.	Face Dimension in Wall	
	Height, in.	Length, in.
2, 4, 6 & 8	4	8 & 12
2, 4, 6 & 8	5⅓	8 & 12
2, 4, 6 & 8	6	12
2, 4, 6 & 8	8	12 & 16②

① Nominal sizes include the thickness of the standard mortar joint for all dimensions.
② 16-in. lengths in 2 and 4 in. thicknesses only.

Structural Clay Partition Tile. To date (1950), modular sizes of partition tile have not been established by ASA Committee A62. Non-modular partition tile, face dimension 12 in. by 12 in., are produced in thicknesses of 2 in., 3 in., 4 in., 6 in., 8 in., 10 in., and 12 in.

In certain areas, notably the Southeast and the Southwest, manufacturers have converted their partition tile production to modular sizes and in such areas the dimensions listed above are nominal; i. e., standard dimensions are equal to the nominal dimensions less the thickness of a standard mortar joint, usually ½ in.

In other areas partition tile are produced with nominal face dimensions (11½ in. by 11½ in.) but of full thickness.

Fig. 3-3 shows typical structural clay partition and furring tile.

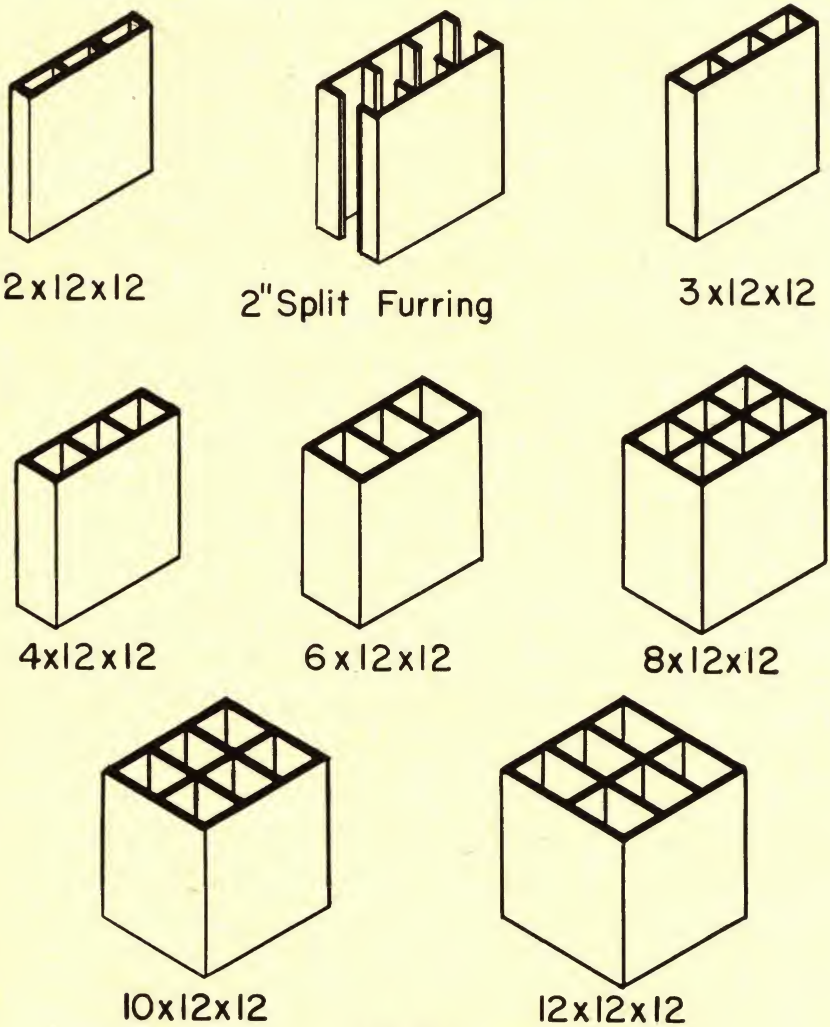


Fig. 3-3
Standard structural clay partition tile

307. COLOR

Natural finished structural clay products are produced in both rough and smooth textures in a wide range of color, from the pure tones of pearl grays or creams through buff, golden and bronze tints to a descending scale of reds, down to purple, maroon and gunmetal black. Glazed and non-lustrous finished facing tile with smooth textures are available in an even wider range of colors.

The chemical composition, including any chemicals which may be mixed with the natural clay, and the degree and method of burning control the color of the finished clay product in the absence of applied coatings, such as glazes or non-lustrous finishes or the introduction into the kiln of chemicals which vaporize and combine with the clays to produce color effects such as are obtained in salt glazing or zinc flashing.

Iron has probably the greatest effect on color of any of the oxides or fluxes commonly found in clays. All clay, regardless of its color, containing iron in practically any form will burn red if exposed to an oxidizing fire. The compound producing the color is ferrous oxide which results from the decomposition of ferrous silicate under oxidizing conditions. This same clay, if burned in a reducing atmosphere, will take on a purple cast due to its ferrous silicate content.

It is possible to neutralize the color effect of iron, providing the iron oxide content is not too high, by adding lime, thereby producing a cream or buff color.

In the paper, "The Color Range of Common Brick", by J. W. McBurney, published in the Journal of the Clay Products Institute of America, June 1932, 182 of Ridgway's color names are used to describe 3582 specimens of building brick. However, 152 of these colors were hues, tints and shades, more or less mixed with gray, of the spectral range red to yellow. Ninety-nine per cent of the building brick production of the United States classifies as reds, buffs and creams. In the one per cent remaining is found almost the complete range of the spectrum.

For the same raw materials and methods of manufacture, the darker colors are associated with harder burning which also tends to decrease absorption and increase compressive strength. However, due to the influence of chemical composition on color, there is obviously no relation between strength and color or between absorption and color that can be applied to products produced from different raw materials.

Since the natural colors of clay products are, with few exceptions, mixtures of shades, rather than pure colors, the accepted practice in specifying color is to require the shipment to match an approved sample.

The appearance of the brick or tile, however, will be greatly affected by the color of the mortar with which they are laid, and it is important, therefore, where color is to be controlled that the approved sample be laid up in mortar similar to that which will be used in the finished structure.

308. TEXTURE

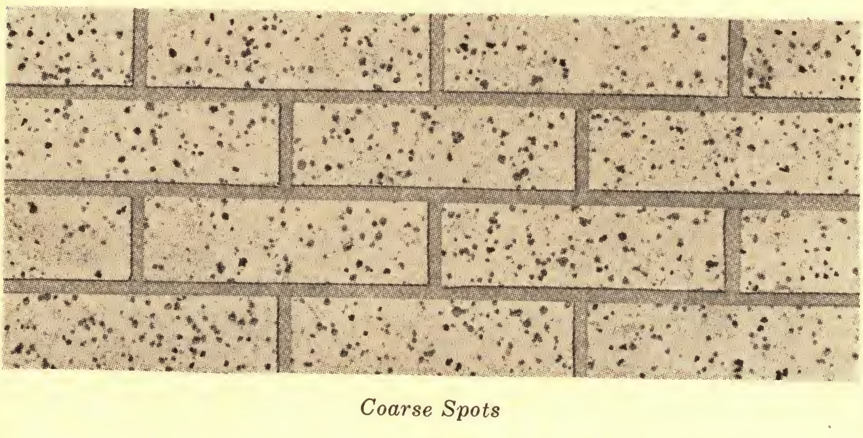
Texture is the surface effect or appearance of the unit apart from the color. Unfortunately, it is practically impossible to give recognizable descriptions of characteristic textures, and as a means of specifying desired textures, the Public Buildings Service of the General Services Administration

has prepared illustrations reproduced from photographs showing ranges (fine, medium and coarse) of the textures generally available and used most extensively throughout the United States. The panels from which these illustrations were made were obtained from the brick display maintained by the Structural Clay Products Institute in cooperation with the Public Buildings Service, which contains over 600 panels from representative manufacturers in every state.

The following plates, 1 to 11, are reproduced through the courtesy of the Public Buildings Service, and are recommended as a most effective means of specifying brick or facing tile texture.

PLATE 1

Medium Spots

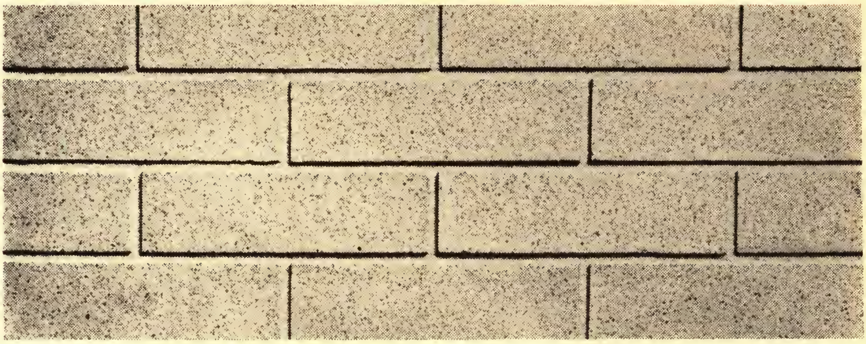


Coarse Spots

IRON SPOTS

Made from plastic clay or shale to which iron pyrites have been added to effect the speckled appearance, although very often no addition of minerals is necessary to the natural clay or shale. The purplish or brown to black spots on salmon, buff, tan, brown or mahogany shade backgrounds are completely blended to present a pleasing appearance.

PLATE 2



Fine Spots

Medium Spots

Coarse Spots

MANGANESE SPOTS

Made similarly to the iron spots, usually from fire clay, and with ground manganese added to obtain the speckled appearance. The desired effect is produced by varying the manganese fineness to obtain the different degrees of spotting as shown. The background is generally gray, but they are also produced in cream, tan or buff uniform colors or ranges.

PLATE 3

Fine Texture

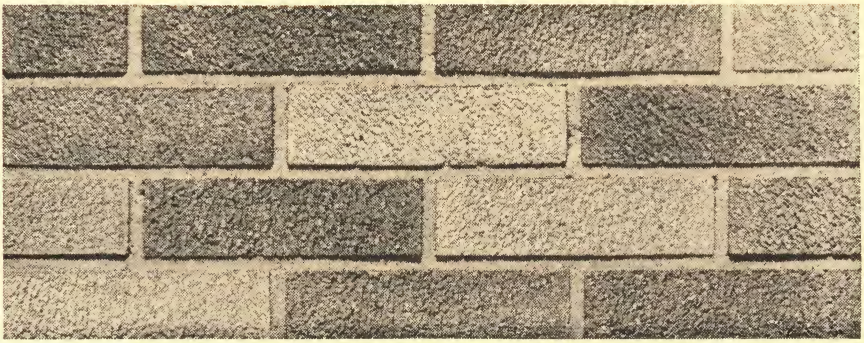
Medium Texture

Coarse Texture

MATT FACE—HORIZONTAL MARKINGS

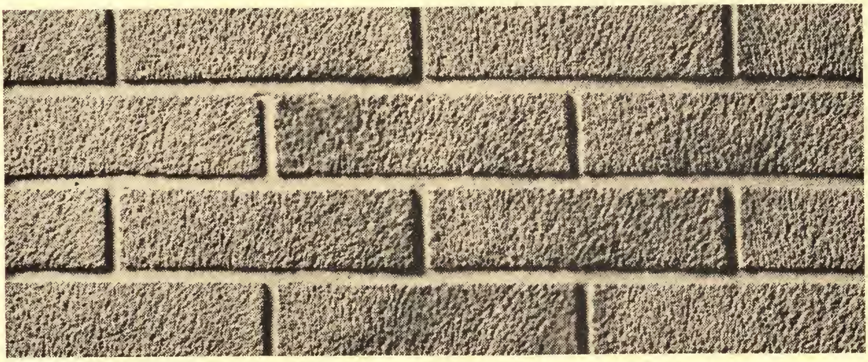
Horizontal matt textures may be obtained in nearly all colors and ranges. The predominant shades are red and buff in all ranges from light to dark in uniform or flashed assemblies of shade and color, but are also furnished in cream, tan and gray to brown, purple, tan, gunmetal, black and polychrome.

PLATE 4



Fine Texture

Medium Texture

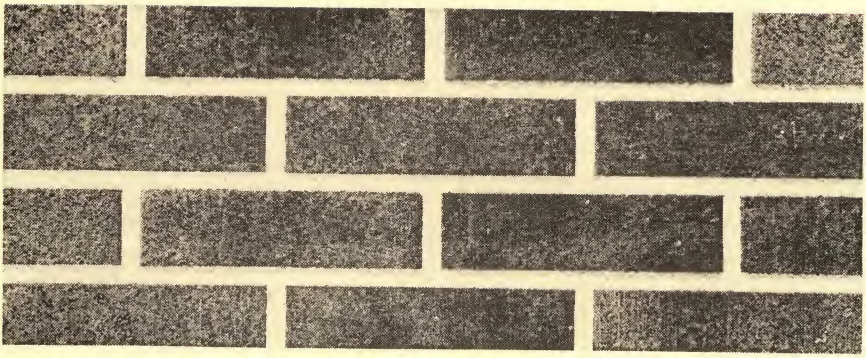


Coarse Texture

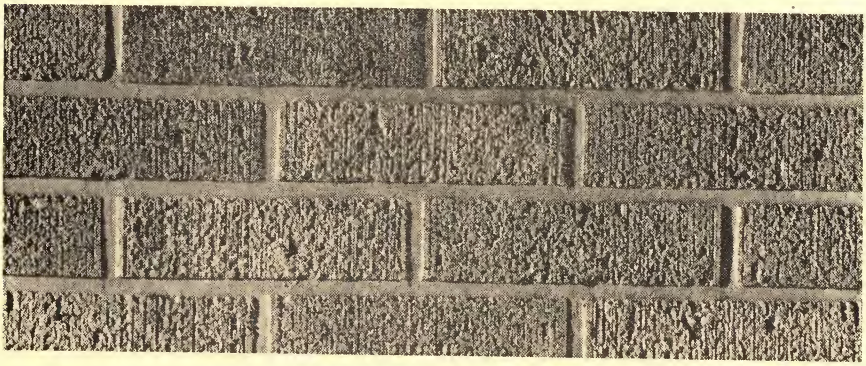
MATT FACE—VERTICAL MARKINGS

The vertical matt texture brick are extremely popular and include various designs of marking from the fine conservative to the coarse or rugged, as desired. They are produced in all shades and colors described for the horizontal matt texture and are universally available.

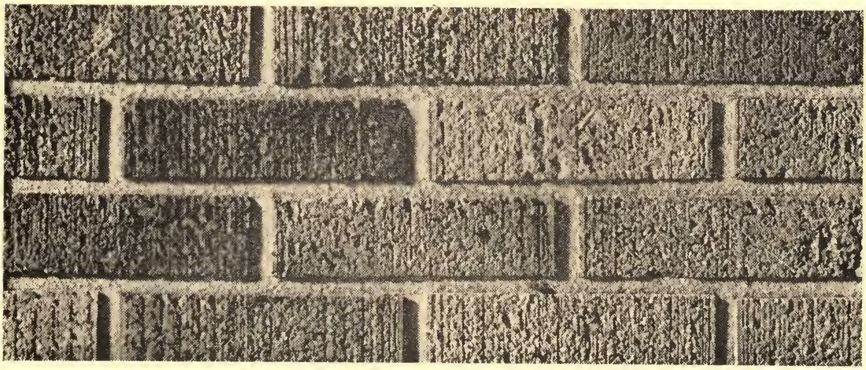
PLATE 5



Fine Texture



Medium Texture



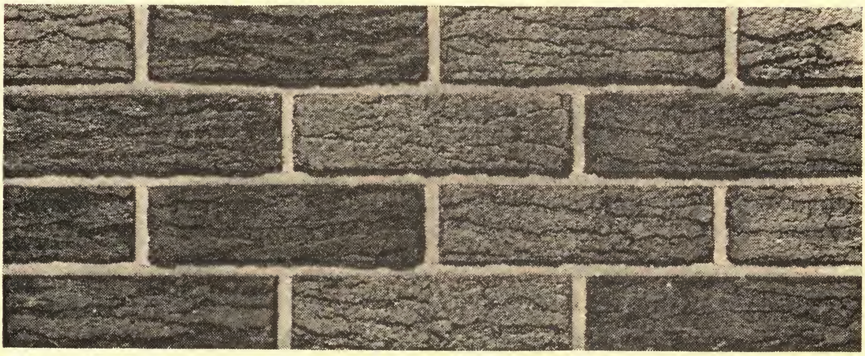
Coarse Texture

RUGS

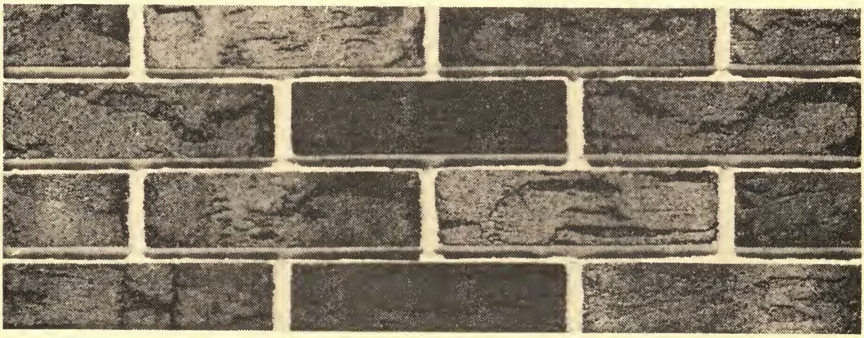
The rug texture is produced by scratching and rolling. Although red or buff plain colors or full mixed shades of them predominate, they may also be obtained in cream, tan and gray, clear or flashed colors and full mingled or variegated ranges. The subdued but definitely vertical grain produces shadows of deep, rich coloring.

PLATE 6

Fine Texture



Medium Texture



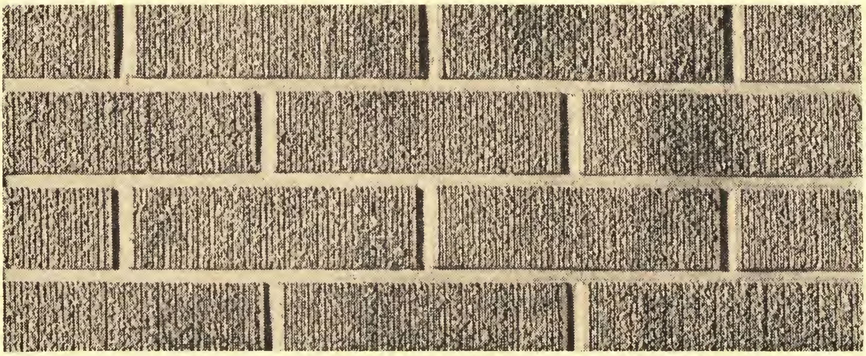
Coarse Texture

BARKS

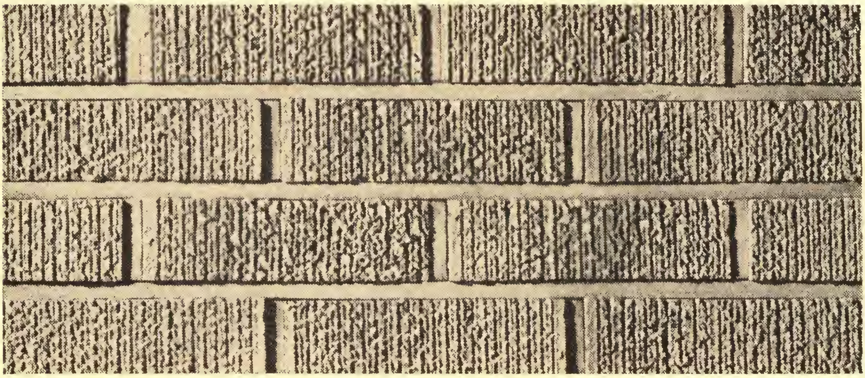
These interesting textures are generally furnished in full mingled ranges, of brown or red. They may also be obtained in tan, green, purple or gray, and frequently in a full range of variegated plain and flashed colors or combinations to simulate bark colors or autumn foliage.

PLATE 7

Fine Texture



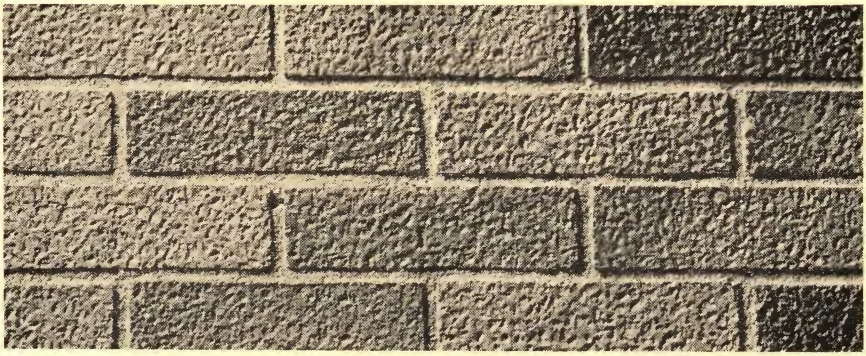
Medium Texture



Coarse Texture

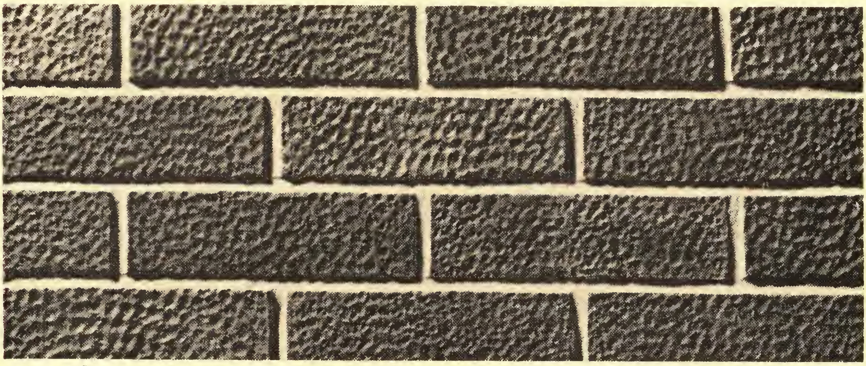
SCORED FACE—VERTICAL MARKINGS

These uniform vertical textured brick are very popular in the mingled light, medium and dark red colors. Some red, with light and dark brown and flashed mixtures are produced, also variegated with red, green and tan to dark brown and black. They are also widely obtained in ivory, and medium and dark golden buff in uniform shades and complete ranges.



Fine Texture

Medium Texture



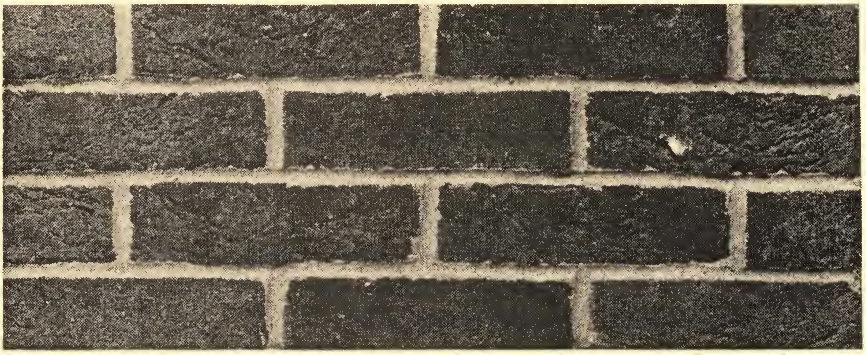
Coarse Texture

STIPPLED—HAMMERED

These textures are usually furnished in full ranges of red and brown, also in uniform colors and the darker blends having flashed brick and red hearts with outlines in various shades of brown. The full range contains light, medium and dark red with brown, with some green and polychrome effects. In certain localities the lighter shades of tan, pink, and buff are available.

PLATE 9

Fine Texture



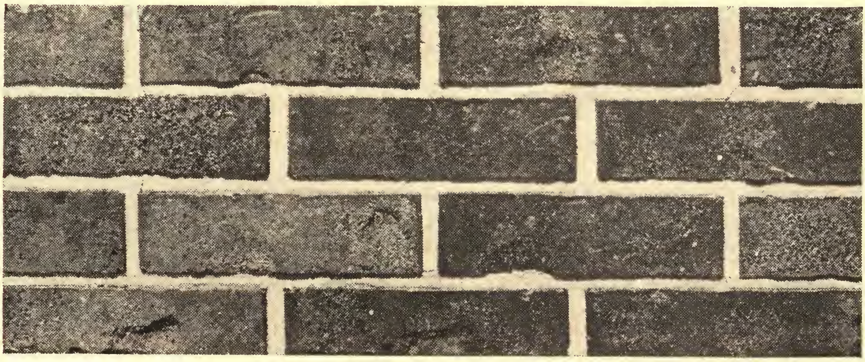
Medium Texture

Coarse Texture

SAND MOLD—CREASED AND FOLDED

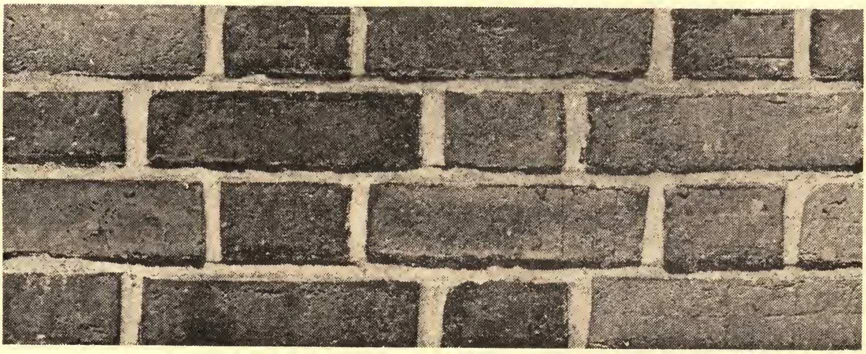
The creases and folds in this type of brick, together with the sand finish, give them a distinct appearance. They are strictly colonial and are generally produced in a range of soft red shades, although deeper red to purple, brown and gunmetal are manufactured in some localities.

PLATE 10



Bar Deformed

Hand Formed

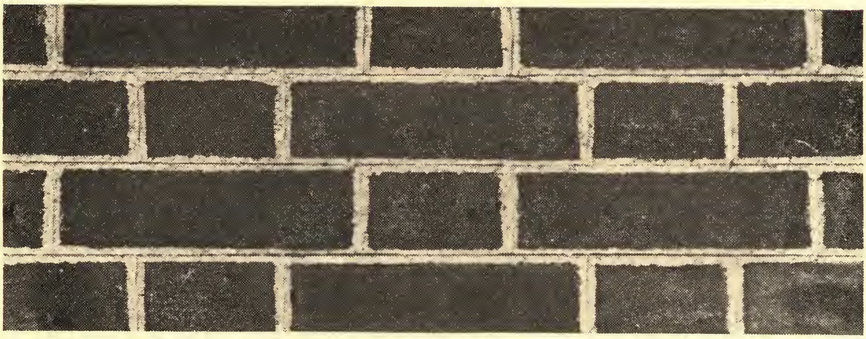


Waterstruck

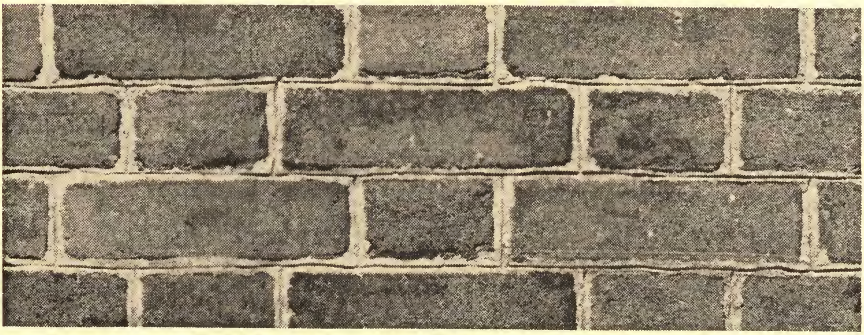
DEFORMED AND WATERSTRUCK

This type of brick has a distinctly individual type of finish produced by the water which is used to lubricate the molds. They are made available in light, medium or deep red mingles, mixed or plain colors as desired, including the well known "Harvards."

PLATE 11



Smooth Texture



Medium Texture

SANDSTRUCK

In the production of this brick, sand is sprinkled in the molds to act as a separater which also results in the very pleasing texture for which the brick is known. They are usually furnished in a blend of colonial reds and often laid with dark headers, but are made available in other color ranges from grayish pink to the darker reds and browns.

SMOOTH

No plain smooth brick surfaces are shown in these reproductions, however, the largest production and selection of colors and quality are available in nearly all localities in this finish. All plain colors, blends, ranges and assemblies, including flashed units, hearts and variegated shades as described for the textured surfaces, may also be obtained in the smooth finish. Many of the rich plain shades resembling different stone surfaces, and the light uniform pastel shades for both exterior and interior use, are available only in the smooth finish brick.

CHAPTER 4

PROPERTIES OF STRUCTURAL CLAY PRODUCTS

401. GENERAL

The sections which follow summarize the information available on various properties of brick and tile. Among the properties considered are those properties depending upon capillary structure, such as porosity and permeability; several strength measures such as compressive, transverse, tensile and shearing strength; such measures of hardness as resistance to abrasion, and miscellaneous properties including elasticity, thermal conductivity, thermal expansion, expansion due to moisture content and, in addition, certain chemical properties such as soluble salt content with its effect on efflorescence.

402. WEIGHT

The true specific gravity of clays and shales used for the production of structural clay products will range from 2.6 for the more porous burning clays to 2.8 for the densest burning material.

The weights per unit volume of representative samples of burned materials vary from 0.060 to 0.082 lb. per cu. in., averaging 0.071 lb. per cu. in. or 123 lb. per cu. ft.

The weight of the burned clay will depend upon the specific gravity of the unburned material and the various processes employed in the manufacture and burning. Since the variation in specific gravity of clays and shales used for the production of structural clay products is small, variations in weight may be attributed largely to methods of manufacture and burning and, consequently, there is a fairly close relationship between total absorption and weight.

Increased density and weight of the burned material is associated with fine grinding, uniform mixing of materials, pressure exerted on the clay as it is extruded, de-airing and hard or complete burning.

403. POROSITY

Porosity and water absorption are not interchangeable terms. Porosity is a volume relation and water absorption is a weight relation. Water absorption, corrected for the specific gravity of the clay, is a measure of the apparent porosity, which may be defined as the ratio of the sum of volumes of the pores (or small cells) which can be filled with water to the total volume of the specimen. The true porosity is the ratio of the sum of all pores or cells to the gross volume of the specimen. The numerical value for apparent porosity tells little about the absorption properties of the clay units. These properties are to a considerable extent determined by the size, shape and number of the pores.

Table 4-1 reproduced from Report of ASTM Committee C-10, Proceedings ASTM, Vol. 24, Part I, page 420, gives the apparent porosities by various ab-

sorption methods, the true porosity by specific gravity and the degree of saturation obtained by different absorption treatments for representative samples of tile units.

The vacuum test is described by Harry D. Foster in his paper "Effectiveness of Different Methods of Making Absorption Determination as Applied to Hollow Building Tile", Journal American Ceramic Society, Vol. 5, No. 11 as follows:

"In order to see whether the pieces which were studied could be more fully saturated and, if so, how much, some were selected at random, redried and placed under a vacuum of 28 in. of mercury. After one half hr. under this reduced pressure, water was admitted to the vacuum chamber and the pieces were allowed to boil for one hr. While the pieces were still immersed the pressure was raised to one atmosphere and the specimens were allowed to remain in the water and cool overnight. On the next day this process was repeated and the percentage absorption obtained."

The **apparent** porosities shown in Table 4-1 are obtained from the formula:

$$\text{Per cent porosity} = \frac{S_a - D}{S_a - S_w} \times 100$$

Where S_a = weight in grams of specimen in air after the absorption treatment.

D = dry weight in grams of specimen.

S_w = weight in grams of specimen suspended in water after the absorption treatment.

Note: $S_a - D$ = grams of water absorbed = volume of water absorbed in cc.

$S_a - S_w$ = weight of water displaced in grams = volume of water displaced in cc. = volume of specimen in cc.

The *true* porosities are obtained from the formula:

$$\text{Per cent porosity} = \frac{(S_a - S_w) - \frac{D}{G}}{(S_a - S_w)} \times 100$$

Where S_a = weight in grams of specimen in air after the absorption treatment.

S_w = weight in grams of specimen suspended in water after the absorption treatment.

D = dry weight in grams of specimen,

G = true specific gravity of specimen. [Standard method of obtaining specific gravity is described in the American Ceramic Society Year Book, 48 (1921-22).]

Note: $S_a - S_w$ = gross volume of specimen in cc.

$\frac{D}{G}$ = volume of solid material in cc.

$(S_a - S_w) - \frac{D}{G}$ = volume of pores in cc.

TABLE 4-1

SATURATION DETERMINATIONS BY FOUR METHODS

Laboratory Identification	Apparent Porosity, Per Cent				True Porosity by Specific Gravity	Saturation, Per Cent			
	72-hr. Cold	1-hr. Boiling	5-hr. Boiling	Vacuum Treatment		72-hr. Cold	1-hr. Boiling	5-hr. Boiling	Vacuum Treatment
K	24.0	28.6	30.2	31.0	31.2	77.1	91.3	96.7	99.4
L	13.5	18.4	19.2	21.5	22.6	59.9	81.3	85.0	95.1
M	17.6	19.3	19.9	21.4	22.6	78.3	85.5	88.4	95.0
N	16.1	22.6	23.7	25.2	26.7	60.3	84.7	88.8	94.3
O	36.3	36.9	38.8	39.5	40.0	90.9	92.5	97.0	99.0
P	18.7	25.5	26.5	27.4	27.9	66.9	91.7	96.7	98.1
Q	16.5	20.4	21.4	21.8	22.5	73.2	90.5	95.0	96.7
R	20.1	22.5	23.2	24.3	24.7	81.3	91.2	94.0	98.4
Average	20.4	24.4	25.3	26.5	27.3	73.5	88.6	92.7	97.0

It will be noted from Table 4-1 that the average apparent porosities as obtained by 1-hr. boiling and 5-hr. boiling are 24.4 per cent and 25.3 per cent, respectively. As a result of the investigations summarized in Table 4-1, the 1-hr. boiling test has been adopted as the standard test for absorption of structural clay tile. Committee C-10 makes the following statement regarding methods of making the absorption test in the report previously cited:

"The results of an investigation made at the National Bureau of Standards to determine the effectiveness of different methods of making absorption determinations indicate that, for specimens of the structure and thickness of hollow tile shells and webs, the 1-hr. boiling as prescribed in the specifications will give the same absorption within one per cent as the 5-hr. boiling treatment.* * * The vacuum treatment, while giving the nearest approach to full saturation, requires equiment that is not generally available where acceptance tests are made. The 1-hr. boiling test is convenient in that it can be completed in one day and can be made with improvised equipment if necessary. If sufficiently large specimens are taken, commercial scales can be used where laboratory equipment is not available."

404. WATER ABSORPTION

The water absorption of a brick or clay tile is defined as the weight of water, expressed as a percentage of the dry weight of the unit, which is taken up by the unit under a given method of treatment. Water absorption is determined by a number of methods, such as partially or totally immersing the unit in cold distilled water for various periods of time ranging from a few min. up to several days; by boiling from one to five hr.; or by treating the unit, while immersed, to alternate applications of vacuum and pressure. All these methods fill the pores more or less completely with water. The boiling and vacuum treatments obviously give a more complete pore filling and hence a higher water absorption than the other methods.

Absorption is obtained from the formula:

$$\text{Per cent absorption} = \frac{W - D}{D} \times 100$$

Where W = weight of specimen after immersion in water
D = dry weight of specimen.

ASTM Standard Method of Sampling and Testing Structural Clay Tile, C112—, provide: "The absorption shall be calculated as a percentage of the initial dry weight carried to the nearest first decimal place."

The absorption of structural clay tile varies over a wide range, and shale, fire clay and surface clay in general vary from low to high absorption in the order named.

Fig. 4-1, reproduced from the 1924 annual report of ASTM Committee C-10, shows the relation of weight of burned material to per cent absorption which, as will be noted, is a fairly constant relationship.

Table 4-2, taken from the paper, "Strength, Water Absorption and Weather Resistance of Building Brick Produced in the United States", by J. W. McBurney and C. E. Lovewell, published in Vol. 33, Part II, of the Proceedings of the American Society for Testing Materials, indicates that 3.87 per cent of all brick tested had water absorptions less than 2.0 per cent

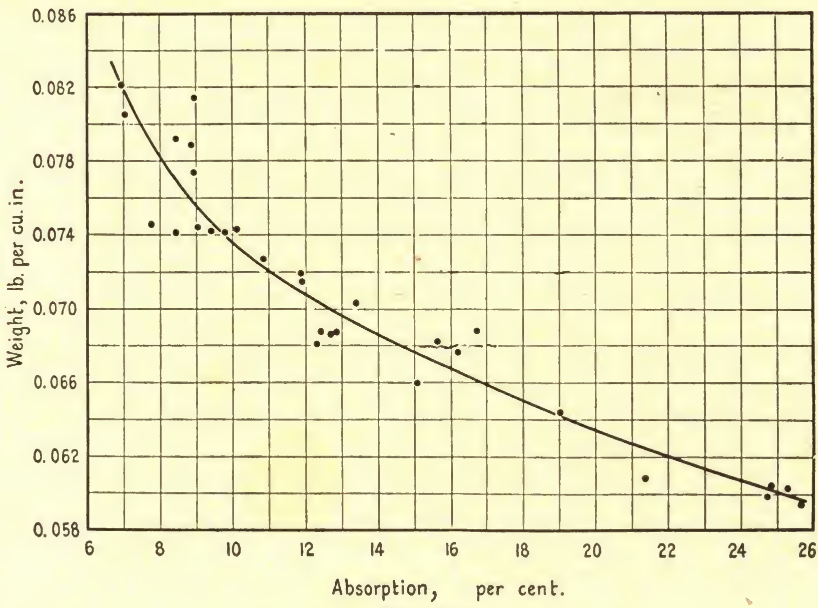


FIG. 4-1

Relation between unit weight of burned material and absorption

TABLE 4-2

DISTRIBUTION OF WATER ABSORPTION AND C/B RATIO FOR BRICK FROM ALL PARTS OF THE UNITED STATES

Water Absorption				Ratio, 48 hr. Cold to 5 hr. Boiling Water Absorption	
Range, per cent	Percentage of Production Within Range			Range	Percentage of Production Within Range
	5 hr. Cold	48 hr. Cold	5 hr. Boiling		
0 to 2.00	3.87	2.65	0.53	0.16 to 0.30	0.37
2.01 to 4.00	8.05	4.96	2.77	0.31 to 0.35	0.45
4.01 to 6.00	14.99	13.00	3.27	0.36 to 0.40	0.21
6.01 to 8.00	13.73	14.22	9.94	0.41 to 0.45	0.64
8.01 to 10.00	16.52	15.82	13.77	0.46 to 0.50	1.28
10.01 to 12.00	11.80	11.77	11.19	0.51 to 0.55	1.17
12.01 to 14.00	11.14	15.29	13.88	0.56 to 0.60	3.30
14.01 to 16.00	8.84	8.24	13.09	0.61 to 0.65	8.64
16.01 to 18.00	5.01	5.52	11.02	0.66 to 0.70	12.37
18.01 to 20.00	2.42	4.77	9.14	0.71 to 0.75	16.80
20.01 to 22.00	2.22	2.31	5.72	0.76 to 0.80	19.41
22.01 to 24.00	1.31	0.64	2.14	0.81 to 0.85	15.65
24.01 to 26.00	0.00	0.68	1.95	0.86 to 0.90	13.89
26.01 to 28.00	0.11	0.00	0.75	0.91 to 0.95	5.32
28.01 to 34.00	0.00	0.11	0.75	0.96 to 1.00	0.51
Total per cent	100.01	99.98	99.91		100.01

The above tabulation is for hard brick, as classified by the manufacturer.

when subjected to 5-hr. cold total immersion. By the same test, only 0.11 per cent exceeded 26.0 per cent absorption, and none in excess of 28 per cent absorption. When water absorption was determined by the 5-hr. boil method, 0.53 per cent of all specimens were under 2.0 per cent absorption and only 0.75 per cent fell within the limits 28.0 to 34.0 per cent. The individual minimum was 0.3 per cent.

Knowledge of the absorption of structural clay products is of importance to the designer in determining whether or not the units should be wetted prior to laying or the application of stucco or plaster and, if the characteristics of the raw materials are known, as indication of the degree of burning. However, a single value of absorption cannot be taken as a measure of burning for units produced from different raw materials.

405. CAPILLARITY AND SUCTION RATE

The pores or small openings in burned clay products function as capillaries which tend to draw water into the unit. This action in a brick is referred to as its initial rate of absorption or suction.

Capillarity or suction rate has little bearing on water transmission through masonry, but it has an important effect on the adhesion or bond between brick and mortar.

Suction rate of clay unit is determined by partial immersion of the unit to a depth of ⅛ in. in water for a period of 1 min. The method of conducting this test is included in ASTM Standard Methods of Sampling and Testing Brick C67—.

Suction rate may be calculated by the following formula:

$$S = \frac{W' - W}{A} \times 30$$

Where S = suction rate, in grams per min.
W = weight of unit prior to partial immersion, in grams.
W′ = weight of unit after partial immersion for one min., in grams.
A = net cross-sectional area of surface of unit immersed, in sq. in.

Note: 1 gram = 0,035 oz. approximately.

Numerous tests of the tensile strength of bond between mortars and brick and of the permeability of brick and tile walls to water penetration indicate that, other factors remaining constant, maximum bond strength and minimum water penetration are obtained with brick having suction rates not exceeding 20 grams (0.7 oz.) per min. when laid.

Suction rates of brick and tile produced commercially vary from 1 to 2 grams per min. to 60 or more grams per min. However, suction rate of units exceeding 20 grams per min. may be reduced to any desired value by wetting prior to laying or before the application of plaster or stucco.

There is no consistent relationship between total absorption and suction rate. Some brick having relatively low absorptions have a high rate of suction and the reverse is also true.

406. PERMEABILITY

Permeability may be defined as the readiness with which a substance permits a fluid to flow through it and is measured by the rate at which a

standard fluid such as water, air or other gas, flows through a mass of unit area and unit thickness. As pressure is necessary to cause the flow, it is necessary to specify the pressure or head of the fluid. Permeability is not necessarily proportioned to porosity, because the shape and distribution of the pores control permeability more than the actual amount of the pore volume. Authorities agree that the permeability of sound brick or tile is a very minor factor in water transmission through masonry. Capillary suction is a force enormously greater than the pressures produced by wind velocity. Consequently, permeability is not controlled by specifications.

407. COMPRESSIVE STRENGTH

The compressive strength of structural clay products is defined as the maximum resistance of the unit to a gradually increasing load applied at right angles to the plane of the bearing surface of the unit.

Compressive strengths of clay and shale brick are reported in the paper, "Strength, Water Absorption and Weather Resistance of Building Brick Produced in the United States", by J. W. McBurney and C. E. Lovewell, previously referred to.

Table 4-3, taken from this paper, is based upon samples representing 37 per cent of the 1929 brick production (clay and shale) of the United States. As indicated, 92 per cent of the brick have flat compressive strengths of 3000 psi or better, excluding salmons. The weighted average of all brick both hard and salmon is 7246 psi; hard brick only, 7434 psi; salmon brick only, 4094 psi. From the distribution data given, approximately 6 per cent of the production classify as 1250 to 2500 psi, 20 per cent as 2500 to 4500 psi, and 74 per cent as 4500 psi or over. Approximately 40 per cent of the production is 8000 psi or over in compressive strength.

TABLE 4-3

DISTRIBUTION OF STRENGTH PROPERTIES OF BRICK FROM ALL PARTS OF THE UNITED STATES

Compressive Strength, Flatwise		Modulus of Rupture	
Range, psi	Percentage of production within range	Range, psi	Percentage of production within range
21001 to 22500	0.46	2101 to 3450	6.95
19501 to 21000	0.69	1951 to 2100	3.00
18001 to 19501	0.46	1801 to 1950	2.74
16501 to 18000	2.04	1651 to 1800	7.57
15001 to 16500	1.49	1501 to 1650	8.34
13501 to 15000	3.71	1351 to 1500	5.34
12001 to 13500	4.76	1201 to 1350	7.12
10501 to 12000	7.78	1051 to 1200	10.55
9001 to 10500	8.61	901 to 1050	10.44
7501 to 9000	11.92	751 to 900	13.60
6001 to 7500	15.47	601 to 750	11.74
4501 to 6000	16.81	451 to 600	7.52
3001 to 4500	17.97	301 to 450	4.35
1501 to 3000	7.46	151 to 300	0.37
0 to 1500	0.36	0 to 150	0.37
Total per cent...	99.99		100.00

The above tabulation is for hard brick, as classified by the manufacturer.

The ratio of compressive strength of clay and shale brick tested on edge to the compressive strength tested flatwise is given in National Bureau of Standards Research Paper No. 59, "The Compressive and Transverse Strength of Brick", by J. W. McBurney, as ranging from .74 to 2.3. In the summary of this paper it is stated: "The tendency of soft mud brick is to give higher unit strengths tested on edge than when tested flat. The 'compacting effect' on the structure of the edge-set brick by the superimposed weight of the other brick in the kiln is offered as a tentative explanation of the tendency toward higher strength on edge."

Average compressive strengths of representative tile are reported by S. H. Ingberg and H. D. Foster in National Bureau of Standards Research Paper No. 37, "Fire Resistance of Hollow Load-Bearing Wall Tile". Based on net area, compressive strengths range from a minimum of 1192 psi to a maximum of 11,349 psi; and based on gross area from 336 psi, the minimum reported for side construction tile, to 5304 psi, the maximum reported for end construction units.

Compressive strength is affected, not only by the raw materials and methods of manufacture used in the production of the tile, but also by unit design.

Fig. 4-2, reproduced from the 1924 Report of ASTM Committee C-10, shows the relation of compressive strength to absorption. For the same unit design, this relationship might be expected to be reasonably constant; however, the same relationship would not be expected to hold for units of different designs which accounts for the scattering of the points in Fig. 4-2.

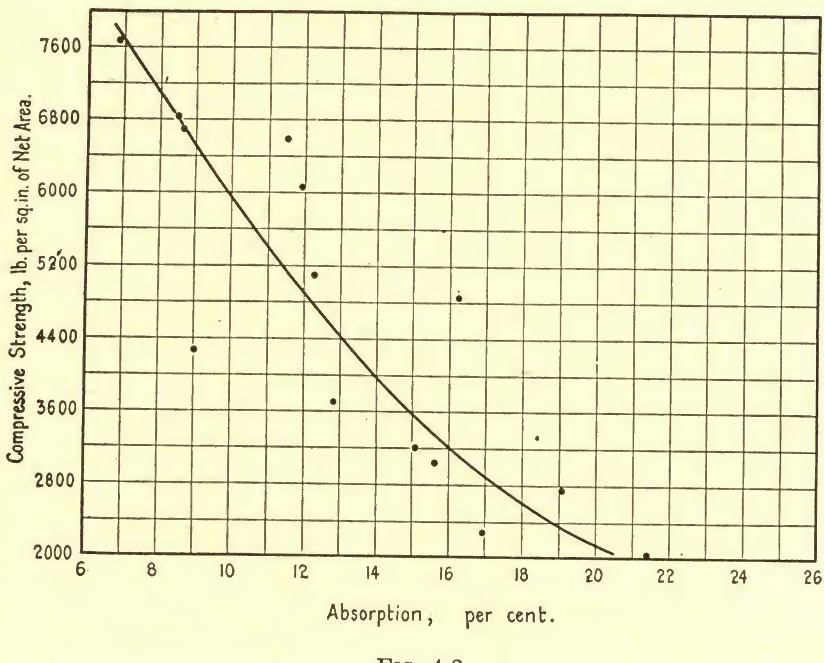


FIG. 4-2

Relation between compressive strength and absorption

Compressive strength of units affects wall strength; however, since it is only one of several factors which determine the compressive strength of masonry walls, wall strength cannot be estimated from unit strength alone.

Methods of estimating wall strength will be discussed in Chapter 6.

As with absorption, compressive strength is an indication of the degree of burning of the unit, provided the relationship has been established for the particular raw material. A single value of compressive strength cannot, however, be applied as a measure of burning to different raw materials.

408. MODULUS OF ELASTICITY AND POISSON'S RATIO

Table 4-4, reproduced from data included in "Strength, Absorption and Freezing Resistance of Hollow Building Units," by H. D. Foster, shows the modulus of elasticity of 18 of the structural tile specimens included in National Bureau of Standards Research Paper No. 37 and Fig. 4-3, reproduced from the 1924 report of ASTM Committee C-10, shows the relation of modulus of elasticity to compressive strength.

As will be noted, in general modulus of elasticity increases with compressive strength to the value of approximately 5000 psi, after which there is little change for tile of higher strengths.

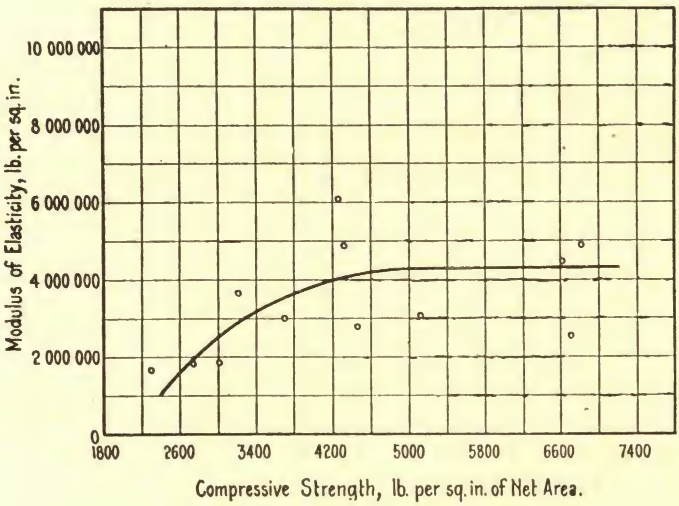


FIG. 4-3

Relation of modulus of elasticity to compressive strength

The committee report states: "The results were obtained with end construction tile tested on end and the modulus of elasticity remains nearly constant until failure is approached with the harder tile; with less dense tile there is a more noticeable decrease in its value after ½ to ¾ ultimate load is applied. The values plotted are of the average tangent to the initial part of the curve."

Table 4-5, reproduced from National Bureau of Standards Technological Paper No. 120, "Tests of Hollow Building Tiles," by Bernard D. Hathcock and

TABLE 4-4

MODULUS OF ELASTICITY OF STRUCTURAL CLAY TILE

Laboratory Identification	Kind of Clay	Source	No. of Tests	Nominal size, in.	Modulus of Elasticity in million psi
A	Shale................	Ind.	4	8x12x12	4.354
G	50% fire clay 50% shale	Ala.	5	8x12x12	4.814
F	Fire clay containing 15% shale.........	Ohio	5	8x12x12	2.731
O	High lime surface clay	Ill.	5	8x12x12	1.620
C	Shale	Iowa	3	8x12x12	6.059
D	Shale	Ky.	5	8x12x12	4.826
M	Dense burning fire clay	Ohio	5	8x12x12	2.426
N	Open burning fire clay	N. J.	5	8x12x12	3.080
P	Open burning fire clay	N. J.	5	8x12x12	2.920
H	Open burning fire clay	Texas	5	8x12x12	1.818
K	Surface clay	N. J.	5	8x12x12	3.595
Q	Surface clay	Mass.	5	8x12x12	4.418
J	Surface clay	N. Y.	5	8x12x12	1.825
B	Shale................	Iowa	3	8x 5x12	4.994
C	Shale................	Iowa	5	8x 5x12	6.059
E	Shale................	Kan.	5	8x 5x12	2.657
L	Dense burning fire clay	Ohio	2	8x 5x12	5.443
M	Dense burning fire clay	Ohio	3	8x 5x12	3.325

TABLE 4-5

COMPRESSIVE STRENGTH, ABSORPTION AND MODULUS OF ELASTICITY OF STRUCTURAL CLAY TILE PRODUCED FROM BUFF BURNING CLAY

Color	Compressive Strength ① psi net area		Per cent Absorption 5 Hour Boiling ②		Modulus of Elasticity, psi ③	
	Average	Range	Average	Range	Average	Range
Dark Buff	7,510	4,650-10,700	5.3	3.8- 6.7	4,519,000	2,830,000-6,160,000
Med. Buff	7,400	4,500-12,360	7.3	5.1- 8.7	4,352,000	3,190,000-6,260,000
Light Buff	5,530	4,820- 7,500	9.3	7.2-10.9	3,074,000	1,880,000-4,170,000

① Compression Tests of Tile on End.
② Results of Approximately 250 Tests.
③ Results of Approximately 114 Tests.

Edward Skillman, gives the modulus of elasticity, absorption and compressive strength for tile produced from buff-burning clays. It will be noted that the values of modulus of elasticity are intermediate between the high values for shale and the low values for surface clay reported in Table 4-4.

The data in Table 4-5 indicate the effect of burning on color, absorption, compressive strength and modulus of elasticity. As the temperature or length of the burning period is increased, clays burn to darker colors, absorption is reduced and compressive strength and modulus of elasticity are increased.

The results of tests at the Watertown Arsenal show modulus of elasticity for building brick ranging from 1,400,000 to 5,000,000 and the ratio of lateral expansion to longitudinal compression (Poisson's ratio) ranging from 0.0434 to 0.114.

Poisson's ratio is rarely a factor of importance to the designer of structural tile walls. However, due to the similarity of the raw materials from which brick and tile are produced and from a comparison of the values of the moduli of elasticity of the two materials as determined by test, the value of Poisson's ratio for tile would probably fall within the range of 0.05 to 0.10.

409. TRANSVERSE STRENGTH (Modulus of Rupture)

The transverse strength of a brick is its resistance to a load when the brick acts as a beam supported at both ends. The value for transverse strength is usually expressed as the Modulus of Rupture. The modulus of rupture is calculated by means of the following formula:

$$MR = \frac{3WL}{2bd^2}$$

Where MR = Modulus of Rupture
W = total load in lbs. at point of breaking
L = span in in. between supports of the brick
b = width of brick, in in.
d = depth of brick, in in.

There is no general rule for converting values of compressive strength to transverse strength and vice versa. Tests at the National Bureau of Standards on transverse strength, reported as modulus of rupture (see Table 4-3), ranged from minimum of 114 psi (a salmon) to a maximum average of 2,890 psi. The lowest average modulus of rupture reported for well-burned brick, where more than one specimen was tested, was 515 psi. Nearly 7 per cent of the samples were reported as exceeding 2101 psi and only 0.37 per cent as less than 150 psi.

410. TENSILE AND SHEARING STRENGTH

Few data have been reported on the tensile and shearing strengths of burned clay products. Tensile strength tests of brick conducted at the National Bureau of Standards provide limited data which indicate that tensile strength is between 30 and 40 per cent of the transverse strength (modulus of rupture) of the unit.

Tensile strength of specimens cut from structural floor tile shells was determined at the University of Texas and reported in Publication No. 4818,

"Investigation of Reinforced Joistile-Concrete Beams," by J. Neils Thompson and W. D. Ramey.

Tensile strength specimens were cut to the size of an ASTM cement mortar briquet, except that the mid section was lengthened to 1 in. These specimens were tested in a standard ASTM briquet testing machine to failure.

Table 4-6 gives the physical properties of the tile from which the tensile strength specimens were cut. Modulus of rupture was determined by testing specimens approximately 2 in. wide, 12 in. long and ⅝ in. thick which had been cut from the tile shells. As will be noted, the tensile strength of the tile listed in Table 4-6 ranges from approximately 20 to 30 per cent of the modulus of rupture.

TABLE 4-6

PHYSICAL PROPERTIES OF TILE USED

Tile	Description	Absorption, 1 hr. boil per cent	Compressive Strength, psi	Modulus of Rupture, psi	Tensile Strength, psi	Modulus of Elasticity	
						in Compression, million psi	in Tension, million psi
A	Buff color, dense, very uniform, no pits or cracks.	5.7	12,440	2,630	818	3.0	3.0
B	Red color, light, not very uniform, numerous pits and cracks.	12.2	4,160	1,190	566	2.1	2.7
C	Dark red color, dense uniform, few pits and cracks.	12.7	12,110	1,210	656	2.6	2.3
D	Medium red color, medium weight, non-uniform, number of small rocks and clay balls in the makeup.	8.3	9,900	1,665	604	3.0	3.2

Punching shear tests on brick and tile indicate strengths in shear of from 30 to 45 per cent of the net compressive strength of the unit.

411. HARDNESS AND RESISTANCE TO ABRASION

The terms, "hard" and "soft," are used rather loosely when applied to clay products. Usually these terms are intended to be synonymous with well-burned and under-burned, respectively; however, the more descriptive terms, "well-burned" and "under-burned," are to be preferred.

The Brinell hardness of brick has been measured, and was reported by J. W. McBurney; "The Relation of Brinell Hardness and Transverse Strength to the Compressive Strength of Building Brick," Journal of the American Ceramic Society, Vol. 13, No. 11, November 1930. There was a slightly better relation between Brinell hardness and flat compressive strength than there was between transverse strength and flat compressive strength.

The resistance to abrasion of brick is affected by the degree of burning and by the nature of the raw material. The degree of resistance varies from extremely under-burned salmons at the low end, to the resistances of

vitrified shale and fire clay brick which are notably high. In general, it can be said that brick cover much of the same range of resistance to abrasion as that obtained in natural building stones.

The abrasive resistance of various types of brick are reported in the paper, "Relation of Water Absorption and Strength of Brick to Abrasive Resistance," by J. W. McBurney, R. H. Brink, and A. R. Eberle in the 1940 Proceedings of the American Society for Testing Materials, Vol. 40, Page 1143. Table 4-7 is reproduced from this report.

TABLE 4-7

ABRASIVE LOSS, STRENGTH AND WATER ABSORPTION OF BRICK SELECTED FROM THE 1936 EXPOSURE TEST

Description of Brick			Results of Tests									
Speci-men No. ①	Locality	Method of Forming and Raw Materials	Abrasive Loss, g.		Compres-sive Strght. Flatwise, psi		Modulus of Rupture, psi		Water Absorption, per cent			
									24-hr. cold		5-hr. boiling	
			Test C	Test D	Test C	Test D	Test C	Test D	Test C	Test D	Test C	Test D
1	Texas	DP, C	6.4	.....	3230	.....	775	.....	22.7	.....	31.0	.....
2	Wisconsin	SC, C	5.9	.....	4245	.....	1160	.....	23.0	.....	26.0	.....
3	Pennsylvania	SM, C	27.2	25.6	1440	1265	195	216	16.3	16.7	24.0	23.7
4	Hudson Valley	SM, C	18.8	8.7	1580	2460	245	218	22.1	22.3	24.0	24.3
5	Detroit	SM, C	5.9	7.5	4130	3680	625	825	19.9	21.1	21.9	23.9
6	Hudson Valley	SM, C	7.5	5.6	4350	3960	595	1120	17.7	16.6	21.2	21.3
7	New England	SM, C	6.4	4.0	5000	5400	600	850	15.8	13.6	18.2	16.8
8	Philadelphia	EC, C	4.5	3.4	5590	6420	770	860	12.7	12.3	17.8	17.3
9	Pennsylvania	SM, C	2.5	.....	5670	.....	1085	.....	11.6	.....	16.3	.....
10	Chicago	EC, C	2.0	.....	3650	.....	1660	.....	12.1	.....	15.9	.....
11	New England	SM, C	3.2	2.5	9200	6570	1365	665	13.2	14.1	15.6	17.3
12	Virginia	DP, C	9.2	5.8	3920	3900	405	915	12.7	10.8	15.1	13.5
13	Texas	DP, S	2.2	1.9	7370	6540	775	810	12.8	12.7	14.3	14.2
14	Maryland	SC, C	5.7	4.5	4190	4720	335	471	9.6	9.1	12.8	12.5
15	West Virginia	SC, S	1.7	.....	5670	.....	1495	.....	10.2	.....	11.8	.....
16	Baltimore	SC, C	1.3	1.9	9230	6790	1000	762	9.8	10.7	11.5	12.7
17	Pennsylvania	SC, S, D	2.3	.....	6540	.....	540	.....	9.4	.....	11.0	.....
18	Iowa	SC, S, D	1.1	0.9	16330	9570	820	700	3.2	2.4	8.8	10.7
19	New England	SM, C	1.0	0.8	11600	12140	1364	1725	4.6	4.9	7.3	8.1
20	New England	SM, C	0.4	0.6	13500	14200	1170	1690	3.8	1.4	5.7	2.3
21	West Virginia	SC, S	0.9	0.7	11750	12700	2015	2605	3.2	2.3	5.5	4.2
22	Pennsylvania	SC, FC	0.1	0.6	14730	13780	2335	2930	0.7	0.7	2.2	2.0

DP (Dry press), SC (Side cut), SM (Soft mud), EC (End cut), C (Clay), S (Shale), D (De-aired), FC (Fire clay).

① Brick arranged in order of decreasing absorption by 5-hr. boiling of Test C.

The authors conclude:

"1. The abrasive resistance of brick increases with their compressive strength. Plotting abrasive loss against compressive strength gave points which fall in a band of hyperbolic form.

"2. The abrasive resistance of brick decreases as water absorption increases. This relation is rather definite for brick with absorption by 5-hr. boiling less than 10 per cent. Above 10 per cent the scatter becomes very large.

"3. Under the conditions of test, abrasive losses determined on brick saturated with water were not significantly greater than those determined on the same brick tested dry."

412. RESISTANCE TO FREEZING AND THAWING

The weathering action that has the greatest effect on most building materials is alternate freezing and thawing in the presence of moisture. This

is practically the only action of weathering that has any significant effect upon burned clay products.

Experience has indicated that any well burned brick or tile will resist the action of freezing and thawing over a long period of time and from a structural standpoint may be considered durable.

There is a reasonably close correlation between the performance of structural clay products in the freezing and thawing test and under the agents of weathering in masonry structures, and at the present time (1950) this test appears to be the best measure of the durability of brick and tile.

Freezing and thawing tests consist of subjecting the unit (or portions of it) to from 50 to 100 alternate cycles of freezing and thawing in the presence of moisture, which requires a period of over 10 weeks and makes the freezing and thawing test impractical as an acceptance test. For this reason, extensive research has been carried on to correlate other physical properties of brick and tile with their resistance to the freezing and thawing test.

For brick produced of the same raw material and by the same method of manufacture, either compressive strength or total absorption may be taken as fairly accurate measures of the resistance of such brick to the freezing and thawing test; however, limits on these properties that apply to one product do not apply to products produced from different raw materials or by different manufacturing processes, and consequently they alone cannot be used as measures of durability in general specifications. A third property known as "saturation coefficient", when used in conjunction with compressive strength and total absorption by 5-hr. boiling, has been found to provide a means of predicting the resistance of most types of brick to freezing and thawing tests with greater accuracy than any other method developed to date (1950).

The saturation coefficient is the ratio of the absorption by 24-hr. submersion in cold water to the absorption after 5-hr. submersion in boiling water and is defined generally as the ratio of easily filled to total fillable pore space. The theory of the saturation coefficient is that if only a part of the total pore space is occupied by water there is room for expansion on freezing into the remaining pore space without disruption of the material. The data indicate that if the easily fillable pore space, that is, the maximum water that might be absorbed by a brick in a wall exposed to moisture, does not exceed 80 per cent of the total pore space, the remaining space will relieve the pressure due to expansion on freezing.

While this theory seems to be applicable to most types of brick, it has been found that it does not apply to certain types of de-aired products. For these products, specifications include requirements for minimum compressive strength or maximum absorption as the best available measures of durability.

Extensive freezing and thawing tests on structural clay tile obtained from 25 separate sources in 12 different states were conducted at the National Bureau of Standards and are reported by ASTM Committe C-10 in its 1924 report. This report states: "No records of unsatisfactory service have been obtained of well burnt tile * * * having absorptions of not more than 16 per cent."

As a result of these tests, maximum absorption requirements are included in specifications for structural clay tile as a measure of resistance to freezing and thawing.

413. THERMAL CONDUCTIVITY

The thermal conductivity of homogeneous materials is affected by several factors. Among these are the density of the material, the amount of moisture present, the mean temperature at which the coefficient is determined, and for fibrous materials, the arrangement of fiber in the material. In general, the thermal conductivity of a material increases directly with the density, increases with the amount of moisture present, and with the mean temperature at which the coefficient is determined.

Structural clay tile and many brick (cored) are not homogeneous materials in the sense that this term is used above, due to the cells enclosed within the perimeter of the unit; however, of the factors listed, density of the burned clay and the mean temperature (average of temperatures on cold and hot sides of panel) particularly affect the thermal conductivity.

Coefficients used in computing heat loss coefficients for structures used for human habitation are as a rule determined at mean temperatures ranging from 40 to 100 degrees F. Where the range of temperature is great the variation of the coefficient of thermal conductance may be an important factor and should be considered in selecting the proper coefficient.

The thermal conductance (C) of structural clay units is not the same as the thermal conductance of brick and structural clay tile masonry, due to the effect of the mortar. Generally speaking, the coefficients for the units will be less than for the masonry. Since the structural engineer is primarily interested in the over-all coefficient of heat transmission for masonry, the thermal conductance coefficients for brick and structural clay tile, listed in the American Society of Heating and Ventilating Engineers' Guide and in other sources, are based on tests of masonry walls and represent the average thermal conductance of the construction. These coefficients are given in Chapter 6.

414. THERMAL EXPANSION

The thermal expansion of clay products varies with the type of raw material and with the temperature range over which the coefficient is determined.

Table 4-8, reproduced from National Bureau of Standards Research Paper No. 1414, "Thermal Expansion of Clay Building Brick", by Culbertson W. Ross, shows the average coefficient of thermal expansion for brick and tile produced from different raw materials. Regarding these values, the author states:

"The coefficients of thermal expansion of 89 per cent of the clay and shale brick were between 5 and 7 millionths per °C (2.8 and 3.9 per °F), the average being 6.1 (3.4). The value, 6 millionths per °C (3.3 per °F), is a good value to assume for the thermal expansion of clay and shale brick, the probable error, as computed from the data of this paper being about 0.7 millionth per °C (0.4 per °F). Of course, if an accurate knowledge of the thermal expansion of any brick is desired, the above assumption could scarcely be substituted for an actual test.

"There was no significant difference between the average thermal expansion of the clay and shale brick. The few values of the coefficient above 7 and below 5 millionths per °C are chiefly limited to the softer clay brick (5-hr. boiling absorption above 14 per cent).

"The thermal expansion of the fire clay brick was much lower than that of the clay and shale brick. The number tested, however, was scarcely large

TABLE 4-8

AVERAGE COEFFICIENT OF THERMAL EXPANSION IN MILLIONTHS PER °C OF DIFFERENT TYPES OF CLAY BRICK

(The value in parentheses are in millionths per °F)

Types of Clay	Number of Specimens	Average Coefficient of Thermal Expansion	Range of Coefficient of Thermal Expansion
Ross (Brick)—10° to 40°C (14° to 104°F)			
Surface Clay	80	6.0 (3.3)	4.2 to 12.4 (2.3 to 6.9)
Shale	41	6.1 (3.4)	4.7 to 6.8 (2.6 to 3.8)
Fire-clay	15	3.9 (2.2)	3.0 to 4.6 (1.7 to 2.6)
Palmer (Brick)—8° to 25°C (18° to 77°F)			
Surface Clay	6	6.6 (3.7)	4.7 to 8.5 (2.6 to 4.7)
Shale	4	4.8 (2.7)	4.1 to 5.2 (2.3 to 2.9)
Fire-clay	4	3.7 (2.1)	3.6 to 3.8 (2.0 to 2.1)
Ingberg (Hollow Tile)—8° to 300°C (32° to 572°F)			
Surface Clay	4	6.2 (3.4)	5.1 to 7.3 (2.8 to 4.1)
Shale	6	6.1 (3.4)	5.7 to 6.9 (3.2 to 3.8)
Fire-clay	6	5.5 (3.1)	3.5 to 6.8 (1.9 to 3.8)
Watertown Arsenal (Brick) 0.6° to 100°C (33° to 212°F)			
Clay & Shale	22	6.3 (3.5)	3.7 to 13.6 (2.1 to 7.6)

enough, nor were the brick representative enough to allow definite conclusions to be drawn as to the thermal expansion of other fire clay brick.

"There was apparently no significant correlation between the thermal expansion and the other physical properties of clay and shale brick which are customarily measured as tests of quality, and even among brick from the same shipment there was no consistent tendency for the thermal expansion to either increase or decrease with differences of hardness of burning."

Table 4-9 is reproduced from data included in National Bureau of Standards Research Paper No. 37, previously referred to, and shows coefficients of thermal expansion over various temperature ranges of 15 of the tile specimens included in the report. The authors state:

"It is seen that the rate of expansion rises with temperature and that the change is particularly marked for the region 500° to 600° C (932° to 1112° F) within which is contained the transformation point of quartz which is accompanied by a relatively large expansion."

For convenience of reference, average values of compressive strength, modulus of elasticity, total flux and lime magnesia content are also included in Table 4-9.

TABLE 4-9

AVERAGE COEFFICIENT OF THERMAL EXPANSION OF DIFFERENT TYPES OF STRUCTURAL CLAY TILE

Source	Coefficient of expansion in millionths per degree C. or F.								Compressive strength (net area on end), psi	Modulus of elasticity, million, psi	Total flux, per cent	Lime magnesia, per cent
	Room to 300° C.	Room to 572.° F.	300 to 500° C.	572 to 932° F.	300 to 600° C.	572 to 1112° F.	500 to 600° C.	932 to 1112° F.				
a	6.93	3.85	9.40	5.22	12.7	7.1	17.5	9.7	4,840	4.350	19.07	4.80
b	5.94	3.30	7.70	4.28	9.3	5.2	12.4	6.9	3,280	4.990	21.70	11.90
c	6.07	3.37	8.05	4.47	9.2	5.1	11.5	6.4	4,290	6.060	18.48	6.20
d	5.89	3.27	10.05	5.58	11.2	6.2	13.7	7.6	6,820	4.830	18.94	3.50
d-1	6.17	3.43	9.60	5.33	11.6	6.4	15.7	8.7			16.04	2.40
e	5.70	3.17	9.85	5.47	12.4	6.9	17.5	9.7	3,580	2.650	17.03	4.53
f	3.55	1.97	7.60	4.22	10.3	5.7	15.6	8.7	4,450	2.730	5.43	1.23
h	6.25	3.47	5.95	3.31	6.4	3.6	7.2	4.0	3,040	1.820	1.39	.62
j	7.11	3.95	9.85	5.47	12.8	7.1	18.8	10.4	2,760	1.830	20.55	9.79
k	5.36	2.98	7.75	4.31	9.7	5.4	13.6	7.6	3,550	3.595	12.48	1.64
l	5.89	3.27	7.85	4.36	9.3	5.2	12.2	6.8	4,840	4.540	9.25	1.28
m	6.83	3.79	5.75	3.19	6.8	3.8	8.8	4.9	5,170	3.330	4.23	1.00
n	5.38	2.99	6.95	3.86	8.7	4.8	12.1	6.7	5,400	3.050	7.41	.77
o	7.32	4.07	10.50	5.83	12.8	7.1	17.3	9.6	2,300	1.620	21.33	15.40
p	4.84	2.69	6.15	3.42	8.3	4.6	12.6	7.0	3,700	2.920	5.90	.72
q	5.07	2.82	7.60	4.22	9.0	5.0	11.9	6.6	6,640	4.420	16.29	4.20

415. EXPANSION DUE TO WETTING

Expansion due to wetting of well burned clay products is not an important factor in the design of brick and tile structures and is so small as to be hardly measurable. In fact, much greater refinement must be employed in the methods of determining the expansion of clay products due to wetting than is customarily used in testing structural materials.

Table 4-10, compiled from data reported in National Bureau of Standards Research Paper No. 321, "Volume Changes in Brick Masonry Materials", by L. A. Palmer, shows the expansion of various types of brick during one month's immersion in water. The degree of burning indicated in this table as "hard" or "soft" represents the manufacturer's rating and, as will be noted from the absorptions, is relative only. The so-called soft grades of brick 2 and 5 have lower absorptions than the hard grades of brick 1, 7 and 8.

Regarding these expansions, the author states: "It is seen that neither hard nor soft burned brick of types 2 and 5 expanded measurably during a month's soaking."

TABLE 4-10

EXPANSION OF BRICK DUE TO WETTING

Brick No.	Description	Absorption range, 48-hr. cold	Degree of Burning	Expansion Wetting in./in.
1	DP, S and C	11.5-17.5	Hard Soft	.000027 .000125
2	SMSC and S	5.2-10.7	Hard Soft	.000005 .000005
3	SMSC and S	6.0-11.5	Hard Soft	.000005 .00005
4	DP and C	9.5-16.0	Hard Soft	.000005 .00003
5	DP and FC	4.2- 9.0	Hard Soft	.000005 .000005
6	SMSC and FC	4.5- 9.8	Hard Soft	.00003 .00010
7	DP and C	18.4-25.1	Hard Soft	.00020 .00025
8	SM and C	19.4-25.6	Hard Soft	.00006 .00015

DP (Dry press), SMSC (Stiff mud side cut), SM (Soft mud), S (Shale), C (Clay), FC (Fire clay).

Tests to determine the expansion of clay and concrete drain tile due to increase in temperature and moisture content are reported by Dalton G. Miller and Charles G. Snyder in Agricultural Engineering, May 1944.

Changes in the length of 24 samples each of 6-in. clay drain tile and 6-in. concrete drain tile were determined after the tile had been immersed in water for 28 days.

The absorption by 5-hr. boil of the 6-in. clay drain tile varied from 23.1 per cent to 1.7 per cent with an average absorption of 9.7 per cent and the average expansion due to wetting is reported as 0.000047 in. per in.

The absorption by 5-hr. boil of the concrete drain tile ranged from 15 per cent to 8.2 per cent with an average value of 10.1 per cent and the expansion due to wetting is reported as 0.00046 in. per in., approximately 10 times the expansion of the clay drain tile.

416. EFFLORESCENCE

Efflorescence on brick masonry walls is usually a light powder or crystallization, caused by water soluble salts, deposited on the surface upon evaporation of the water. Some of the salts frequently found in efflorescence are calcium sulfate (gypsum), magnesium sulfate (epsom salts), sodium chloride (table salt), sodium sulfate and potassium sulfate. There are two general conditions necessary to produce efflorescence: (1) soluble salts present in the wall materials, and (2) moisture to carry these salts to the surface.

Soluble salts may be present in masonry units, mortar or plaster. Only a very small percentage of the brick produced in the United States contain sufficient water soluble salts to contribute to efflorescence.

Wick tests were made on 684 brick at the National Bureau of Standards in 1930 to determine their tendency to efflorescence. These tests are referred to in the paper, "The Wick Test for Efflorescence of Building Brick", by J. W. McBurney and D. E. Parsons, ASTM Proceedings, Vol. 37, page 332. They indicate that 83 per cent or 5/6ths of all the brick samples did not constitute a source of efflorescence. If the results were weighed according to production, the percentage free from efflorescence would be greater. It is probable that approximately 90 per cent of the brick production in this country will not contribute to efflorescence.

Second-hand brick, because of their uncertain origin and previous contact with mortar and plaster, may be a source of efflorescence. Mortars and plasters are frequently the source of efflorescence due to one or more of the ingredients.

At the June 1942 meeting of ASTM Committee C-15, ASTM Specification C67—, Standard Methods of Sampling and Testing Brick, was amended to include a standard test for efflorescence. This test is known as the wick test for efflorescence and is described in the Standard Method of Tests as follows:

"One specimen from each of the five pairs shall be set on end, partially immersed in distilled water to a depth of approximately 1 in. for 7 days in the drying room. When several specimens are tested in the same container, the individual specimens shall be separated by a space of at least 2 in.

"Note 1. Testing specimens from different sources simultaneously in the same container is not recommended, because specimens with a considerable content of soluble salts may contaminate the salt-free specimens.

"Note 2. The pan or trays should be emptied and cleaned after each test.

"The second specimen from each of the five pairs shall be stored in the drying room without contact with water.

"At the end of 7 days, the first set of specimens shall be inspected and both sets shall then be dried in the drying oven for 3 days.

"Note 3. A drying period of 24 hr. is sufficient for the purpose of an efflorescence test. A 3-day period of drying prepares the specimens for the other tests (modulus of rupture, compressive strength, absorption, and initial rate of absorption) that may be specified."

The method of rating the specimens after the test is specified as follows:

"After drying, each pair of specimens shall be examined and compared, observing the top and all four faces of each specimen. If there is no observable difference due to efflorescence, the rating shall be reported as 'no efflorescence.' If any difference due to efflorescence is noted, the specimens shall be viewed from a distance of 10 ft., under an illumination of not less than 50 foot-candles, by an observer with normal vision. If under these conditions no difference is noted, the rating shall be reported as 'slightly effloresced.' If a perceptible difference due to efflorescence is noted under these conditions, the rating shall be 'effloresced.' The appearance and distribution of the efflorescence shall be recorded."

417. MISCELLANEOUS PROPERTIES

Sound Absorption. Most structural clay products as now (1950) produced commercially, like other structural masonry materials, absorb but little sound due to their density and the high degree of imperviousness of their surfaces. Sound absorption of dense de-aired brick or tile is of the order of 1 to 3 per cent. However, units having sound absorptions of 20 to 40 per cent at 512 cycles per second have been produced experimentally and to a limited degree commercially. Further advances in this field may be expected.

Electrical Conductivity. Electrical conductivities of building brick range from 0.5 to 11 microamperes at 25.1 kv. Since this is of the order of air, the electrical conductivity of structural tile might be expected to be the same.

CHAPTER 5

MORTAR

501. SPECIFICATIONS

The following specifications cover 3 types of mortar for use in the construction of reinforced and unreinforced unit masonry structures. Two alternate specifications—property and proportion—are given, only one of which should apply to a single purchase.

The acceptability of mortar under the property requirements is determined by laboratory tests and is based upon (1) the properties of the ingredients (materials) mixed within a specified range of ratio of aggregate to cementitious materials and (2) properties (water retention and compressive strength) of mortar mixed in the testing laboratory of the same materials and in the same proportion, except water, that will be used in the construction.

The acceptability of mortar under the proportion requirements is determined by the proportions of the dry mix and is based upon the properties of the ingredients (materials) and limitations on the proportions of cementitious materials and aggregate.

For important work it is recommended that the property specifications be used. It is believed that the alternate proportion specifications will produce satisfactory mortar; however, they may not result in the lowest cost mortar that will be satisfactory for the use intended.

Contract specifications should include the following information:

1. The applicable specifications (property or proportion).
2. Type of mortar required (A, B, or C).
3. If pre-hydrated mortar is required, so state.

502. PROPERTY SPECIFICATIONS FOR MORTAR

1. MATERIALS

Materials used as ingredients in mortar shall conform to the requirements specified in the following paragraphs (a) to (g):

(a) Cementitious Materials. Cementitious materials shall conform to the appropriate American Society for Testing Materials Specifications as follows:

Portland Cement. Standard Specifications for Portland Cement, Type I, II or III (ASTM Designation: C150-), or Tentative Specifications for Air-Entraining Portland Cement, Type IA or IIA (ASTM Designation: C175-).

Masonry Cement. Tentative Specifications for Masonry Cement (ASTM Designation: C91-).

Quicklime. Standard Specifications for Quicklime for Structural Purposes (ASTM Designation: C5-).

Hydrated Lime. Tentative Specifications for Hydrated Lime for Masonry Purposes, Type S (ASTM Designation: C207-).

(b) Aggregates. Standard Specifications for Aggregate for Masonry Mortar (ASTM Designation: C144-).

(c) Water. Water shall be clean and free of deleterious amounts of acids, alkalies, or organic materials.

(d) Admixtures. Integral waterproofing compounds or other admixtures not mentioned in the specifications shall not be used in mortar for use in reinforced brick masonry without approval in writing from the purchaser.

(e) Mortar Colors. Only pure mineral mortar colors shall be used. The brand and quality of such coloring, and the amount to be used shall, unless stipulated in the specifications, be approved in writing by the purchaser.

(f) Anti-Freeze Compounds. No anti-freeze liquid, salts or other substances shall be used in the mortar to lower the freezing point.

(g) Storage of Materials. Cementitious materials and aggregates shall be stored in such a manner as to prevent deterioration or intrusion of foreign material. Any material that has become unsuitable for good construction shall not be used.

2. MEASURING AND MIXING

(a) Measurement of Materials. The method of measuring materials for the mortar shall be such that the specified proportions of the mortar materials can be controlled and accurately maintained during the entire progress of the work.

(b) Mixing Mortars. Cementitious materials and aggregate shall be mixed with the maximum amount of water consistent with satisfactory workability for a minimum period of 3 min. in a drum type batch mixer. Hand mixing of the mortar may be permitted on small jobs, with the written approval of the purchaser outlining hand mixing procedure.

(c) Mixing Grout. Grout shall consist of mortar meeting the applicable specification requirements to which sufficient additional water is added to cause the mixture to flow readily.

(d) Mixing Pre-hydrated Mortar. When specified by the purchaser, mortar shall be pre-hydrated by mixing the dry ingredients (cementitious materials and aggregate) with only sufficient water to produce a damp mass of such consistency that it will retain its form when pressed into a ball with the hands, but will not flow under the trowel. The mortar shall then be allowed to stand for a period of not less than 1 hr. nor more than 2 hr., after which it shall be remixed with the addition of sufficient water to produce satisfactory workability.

(e) Aggregate Ratio. The damp loose volume of aggregate in mortar shall be not less than 2¼ times nor more than 3½ times the total separate volumes of cementitious materials used.

3. MORTAR PROPERTIES

(a) Water Retention. Mortar of the materials and proportions (except water) used in the construction shall have a flow after suction of not less than 70 per cent.

(b) Compressive Strength. The average compressive strength of three 2-in. cubes of mortar shall be not less than the strength shown in Table 5-1 for each mortar type specified.

TABLE 5-1

COMPRESSIVE STRENGTH OF MORTAR

Mortar Type	Average Compressive Strength, psi.	
	At 7 days	At 28 days
A	1500	2500
B	550	900
C	200	350

4. SAMPLING AND TESTING

(a) Sampling. Mortar for testing shall be mixed in the laboratory of representative samples of the materials (cementitious materials and aggregate) that will be used in the construction and in the same proportions, except water. Grout shall be tested as mortar.

Not less than one sample of mortar shall be tested for water retentivity and at least three 2-in. cubes of mortar shall be made and tested as the work progresses for each lot of 50,000 brick equivalent or fraction thereof.

(b) Testing. Water retentivity and compressive strength of mortar shall be determined in accordance with the test procedures described in Tentative Specifications for Masonry Cement, ASTM Designation C91- .

Acceptance of the mortar shall be based initially upon water retentivity and both 7-day and 28-day strength tests. Subsequent approvals (check tests) may be based upon water retentivity and 7-day strength tests, provided the ingredients used are of the same brands or from the same source of supply as those used in the mortar originally approved.

5. COSTS OF TESTS

Unless otherwise specified in the purchase order, the costs of tests shall be borne as follows:

(a) If the results of the tests show that the mortar does not conform to the requirements of these specifications, the cost shall be borne by the seller.

(b) If the results of the tests show that the mortar does conform to the requirements of these specifications, the cost shall be borne by the purchaser.

503. PROPORTION SPECIFICATIONS FOR MORTAR

1. MATERIALS

Materials used as ingredients in mortar shall conform to the requirements specified in the following paragraphs (a) to (g):

(a) Cementitious Materials. Cementitious materials shall conform to the appropriate American Society for Testing Materials Specifications for the material as follows:

Portland Cement. Standard Specifications for Portland Cement, Type I, II or III (ASTM Designation: C150-), or Tentative Specifications for Air-Entraining Portland Cement, Type IA or IIA (ASTM Designation: C175-).

Masonry Cement. Tentative Specifications for Masonry Cement (ASTM Designation: C91-).

Quicklime. Standard Specifications for Quicklime for Structural Purposes (ASTM Designation: C5-).

Hydrated Lime. Tentative Specifications for Hydrated Lime for Masonry Purposes, Type S (ASTM Designation: C207-).

(b) Aggregates. Standard Specifications for Aggregate for Masonry Mortar (ASTM Designation: C144-).

(c) Water. Water shall be clean and free of deleterious amounts of acids, alkalies, or organic materials.

(d) Admixtures. Integral waterproofing compounds or other admixtures not mentioned in the specifications shall not be used in mortar for use in reinforced brick masonry without approval in writing from the purchaser.

(e) Mortar Colors. Only pure mineral mortar colors shall be used. The brand and quality of such coloring, and the amount to be used shall, unless stipulated in the specifications, be approved in writing by the purchaser.

(f) Anti-Freeze Compounds. No anti-freeze liquid, salts or other substances shall be used in the mortar to lower the freezing point.

(g) Storage of Materials. Cementitious materials and aggregates shall be stored in such a manner as to prevent deterioration or intrusion of foreign material. Any material that has become unsuitable for good construction shall not be used.

2. MEASURING AND MIXING

(a) Measurement of Materials. The method of measuring materials for the mortar shall be such that the specified proportions of the mortar materials can be controlled and accurately maintained during the entire progress of the work.

(b) Mixing Mortars. Cementitious materials and aggregate shall be mixed with the maximum amount of water consistent with satisfactory workability for a minimum period of 3 min. in a drum type batch mixer. Hand mixing of the mortar may be permitted on small jobs, with the written approval of the purchaser outlining hand mixing procedure.

(c) Mixing Grout. Grout shall consist of mortar meeting the applicable specification requirements to which sufficient additional water is added to cause the mixture to flow readily.

(d) Mixing Pre-hydrated Mortar. When specified by the purchaser, mortar shall be pre-hydrated by mixing the dry ingredients (cementitious materials and aggregate) with only sufficient water to produce a damp mass of such consistency that it will retain its form when pressed into a ball with the hands, but will not flow under the trowel. The mortar shall then be allowed to stand for a period of not less than 1 hr. nor more than 2 hr., after which it shall be remixed with the addition of sufficient water to produce satisfactory workability.

(e) Minimum Aggregate Ratio. The damp loose volume of aggregate in the mortar shall be not less than 2¼ times the total separate volumes of cementitious materials used.

3. MORTAR PROPORTIONS

(a) Proportion. Mortars shall be proportioned by volume for the type specified within the limits prescribed in Table 5-2.

TABLE 5-2

MORTAR PROPORTIONS BY VOLUME ①

Mortar Type	Cement, bags (cu. ft.)	Lime			Aggregate Damp Loose, cu. ft. Not more than
		Hydrated Lime, bags (50 lb.)		Lime Putty, cu. ft.	
A	1 (Portland)	¼	or	¼	3
B	1 (Portland)	1	or	1	6
B	1 (Masonry Type II)	—		—	3
C	1 (Portland)	2	or	2	9
C	1 (Masonry Type I)	—		—	3

① For the purposes of these specifications, the weight of 1 cu. ft. of the respective materials used as the ingredients in mortar shall be considered to be as follows:

Material	*Weight per cu. ft.*
Portland Cement	94 lb.
Masonry Cement	weight printed on bag
Hydrated Lime	40 lb.
Lime Putty	40 lb. dry lime solids
Sand, damp and loose	1 cu. ft. contains 80 lb. dry sand

504. RECOMMENDED USES OF MORTAR

(a) General. It should be emphasized that in selecting a mortar for any use, it is necessary to evaluate the desirable properties of the mortar in the light of the use requirements. For this reason it is impossible to specify mortar that will be "best" for all purposes. Certain properties are desirable in all mortars, but it will be found in most instances that it is necessary to emphasize one property possibly at the expense of others.

Desirable mortar properties may be found in mortars consisting of a wide variety of ingredients and proportions, and mortar which can be produced from materials available locally is, as a rule, satisfactory for use with most types of masonry units.

In the recommended specifications, three types of mortar are covered which may be specified on the basis of properties or proportions, and also pre-hydrated mortar which may be similar to any of the three types, but must conform to the additional requirements of pre-hydration.

Recommendations are in general applicable to exposures and construction practices prevailing in the northeastern quarter of the United States. Due to variations in exposures and conditions of use existing in different localities, it may be desirable to expand or restrict the uses of the mortar types listed in certain districts.

(b) Type (A) Mortar. Type (A) mortar is a high strength mortar suitable for general use and recommended specifically for reinforced brick masonry and plain masonry below grade and in contact with earth, such as foundations, retaining walls, walks, sewers, manholes and catch-basins. Specifications for this mortar include a flow after suction requirement of 70 per cent of initial flow as a measure of water retentivity and, to a degree, of workability. This requirement is met by some masonry cements through the addition of water repellents. Due to the effect of these admixtures on bond between

mortar and steel, mortar containing them is not recommended for use in reinforced brick masonry.

(c) Type (B) Mortar. Type (B) mortar is a medium strength mortar suitable for general use in exposed masonry above grade and recommended specifically for parapet walls, chimneys and exterior walls subjected to severe exposures as, for example, on the Atlantic seaboard, and also for exposed and load-bearing structural clay tile construction. In most localities this mortar will be obtainable at lower cost than Type (A) mortar.

(d) Type (C) Mortar. Type (C) mortar is a low strength mortar suitable for non-load-bearing walls of solid masonry units, for interior non-load-bearing partitions of structural clay tile, and for load-bearing walls of solid units in which the compressive stresses developed do not exceed 100 psi and where exposures are not severe; that is, where the masonry will not be subjected to freezing and thawing in the presence of excessive moisture. In most localities this mortar may be obtained at the lowest cost of any of the three types. Due to its low strength, however, it should not be used in construction where high lateral strength is required.

(e) Mortar for Tuck-pointing. Pre-hydrated mortar is recommended for tuck-pointing of masonry walls. The selection of a mortar for this work depends to a large degree on the density of the old mortar. For best results the pointing mortar should not be denser than the original mortar. Rich mixes should be avoided to eliminate excessive shrinkage and volume change after hardening. A high water retention is desired to prevent a rapid loss of water to the brick before tooling and to insure a good bond with the old mortar and brick from the tooling operation. In the absence of information on the density and proportioning of the old mortar, pre-hydrated Type (B) mortar is recommended.

(f) Mortar for Cavity Walls. As with the other types of masonry construction, the mortar requirements for cavity walls depend to a large degree on exposure. However, since the lateral strength of cavity walls is less than the strength of solid walls of the same net cross-sectional area (approximately one-half), wind velocity and other forces producing lateral stresses in the masonry may be determining factors. Type (A) or Type (B) mortar is recommended for use in cavity wall construction. Type (A) mortar is recommended in locations subjected to wind velocities greater than 80 mph.; and in locations where maximum wind velocities are not expected to exceed 80 mph., Type (B) mortar is recommended.

(g) Mortar for Facing Tile. Either Type (A), (B), or (C) mortar is satisfactory for use in laying facing tile in accordance with specification and job requirements; however, for masonry laid with ¼-inch joints, all of the aggregate should pass a No. 16 sieve. Where light colored mortar joints are required, white portland cement and a white aggregate may be used, either to lay up the entire wall or the joints may be raked and tuck-pointed with the light colored mortar.

505. PROPERTIES OF MORTAR

(a) General. A discussion by the author of the ingredients and properties of masonry mortars may be found in the publication of the Struc-

tural Clay Products Institute, "Recommended Mortar for Clay Products Masonry." The following is quoted from the foreword:

"Any discussion of the ingredients and properties of masonry mortars tends to become so voluminous as to be of doubtful value to other than the technologists or specialists in masonry construction. On the other hand, the mere statement of conclusions and recommendations without supporting arguments and data is always open to question, particularly when controversial subjects are involved.

"In an effort to meet this situation, the discussion is prefaced with a summary in which it is attempted to state briefly conclusions and recommendations, the supporting arguments for which may be found in the discussion.

"Recommendations and conclusions are based upon field experience and the technical data now available. In the discussion the author has attempted to include typical data relating to the different properties of mortars, and on controversial subjects particularly, data supporting different viewpoints are presented. However, since the primary purpose of this publication is to aid users of clay products in specifying mortar for clay products masonry, it seemed necessary to make definite recommendations even on controversial questions. It is believed that the mortars recommended will give satisfactory results, but it goes without saying that these recommendations are not the last word on the subject, and as further data are obtained through researches now in progress, further recommendations may be justified."

In the following, only the conclusions on which the foregoing recommendations are based will be given. For a more complete discussion of the subjects covered, the reader is referred to "Recommended Mortar for Clay Products Masonry."

(b) Workability and Water Retentivity. Workability and water retentivity, which to a degree is a measure of workability, are essential properties of mortar for all types of masonry in which impermeability to moisture and strength are important considerations.

Recommended specifications for Types (A), (B) and (C) mortars contain the requirement that flow after suction for 1 min. shall be greater than 70 per cent of the initial flow. Flow after suction is a measure of water retentivity and the requirement included in the specifications is a minimum requirement.

(c) Bond. Bond between mortar and brick is affected by the water retentivity of the mortar, the rate of suction of the brick when laid, the consistency (flow) of the mortar, and the technique of forming the mortar joint.

For maximum bond strength, the water retentivity of the mortar should be high (flow after suction exceeding 70 per cent of the initial flow); the flow of the mortar should be the maximum consistent with workability (use maximum water possible); the suction rate of the brick when laid should be 20 grams (.7 oz.) per minute or less, and the forming of the mortar joint should be accompanied by pressure to insure intimate contact between mortar and the masonry unit. The strength of the bond is further increased by continuous pressure during the setting of the mortar.

(d) Durability. For relatively dry masonry which resists the penetration of excessive moisture, the resistance of mortar to alternate freezing and thawing does not appear to be a serious problem. For masonry subject to severe exposure (alternate freezing and thawing in the presence of exces-

sive moisture), the minimum strength requirements specified for Type (B) mortar are recommended.

(e) **Strength.** Strength of mortar, as determined by 2-in. cubes, affects both the lateral and compressive strength of masonry. Cube strength may be taken as a measure of durability of hydraulic mortars, although this does not hold for feebly hydraulic mortars, non-hydraulic mortars, nor for mortars containing grinding aids or water repellents. Compressive strength of mortar cubes may also be used as a convenient acceptance test for mortar. Specific recommendations as to strength requirements are included in the recommended specifications.

(f) **Volume Change.** Volume change of mortar due to hardening and cyclic wetting and drying is affected by curing conditions, richness of mix and water content. Mortar hardened in absorbent moulds, or in clay products masonry, shows substantially less volume change (approximately 50 per cent) than mortar hardened in non-absorbent moulds. Mortars composed of cementitious material and aggregate in the proportions of 1 to 2 or more by volume, show relatively slight differences in volume change due to cyclic wetting and drying. Mortars richer in cementitious material than 1 to 2 show greater volume change and should be used with caution. Shrinkage, particularly during early hardening, increases with increase in water content of the mortar.

Thermal volume change should be considered in the design of structures, however the differential thermal volume change between masonry materials does not appear to have an important effect upon the performance of masonry structures.

Volume change due to unsound ingredients (containing reactive chemical compounds) may be sufficient to cause disintegration of the masonry. Such ingredients should not be used in masonry mortar.

(g) **Efflorescence.** Mortars containing large amounts of soluble salts will contribute to efflorescence if excessive water penetrates the masonry. At the present time (1950) no standard method of testing mortars for efflorescence tendencies has been accepted nationally.

(h) **Extensibility.** The extensibility of a mortar is the amount per unit of length that the specimen will elongate before rupturing. While this is an important factor in adding resilience to the masonry, the variation in the extensibilities of all mortars used commercially is so slight that this property is not included as a specification requirement.

(i) **Permeability.** Mortars of extremely low permeabilities are required only in hydraulic, below grade and storage type structures. In ordinary masonry walls above grade, the permeability of the mortars recommended is not an important factor.

(j) **Pre-Hydrated Mortar.** Prehydrated mortar may be of any of the three types included in the specifications, provided the technique of mixing the mortar conforms to the requirements for pre-hydration.

While there are few data available on the effect of pre-hydration on mortar properties, experience in the field as well as the laboratory data that have been reported, indicate that pre-hydration increases the plasticity and workability of the mortor, reduces shrinkage, particularly prior to hardening,

and reduces compressive strength slightly. Although the available evidence seems to indicate that the pre-hydration of most mortar for use in plain masonry would be desirable, it is thought that the advantage gained would not justify the added expense. Consequently, the recommended use of pre-hydrated mortar is limited to mortars for tuck-pointing and repairing masonry construction.

506. MORTAR INGREDIENTS

(a) Cementitious Materials. As indicated in the Recommended Specifications for Mortar, cementitious materials (cements and lime) should conform to the appropriate ASTM Specification. In general, it is recommended that all lime for use in masonry mortar be in the form of putty. Exceptions to this rule are specially processed hydrates conforming to the requirements for Type S of Tentative Specifications for Hydrated Lime for Masonry Purposes, ASTM Designation C207- .

(b) Ground Clay. While the laboratory data available on the properties of mortars containing ground clay as a plasticizing agent are limited, particularly as regards water retentivity and plasticity, field experience indicates that satisfactory mortar may be obtained with ground clays or shales as plasticizers if the proportions are within the range of 0.80 to 0.60 parts cement; 0.20 to 0.40 parts ground clay; and 3 parts sand by volume. Since no nationally accepted specifications have as yet been developed for ground clay as an admixture for mortars, the purchaser should be guided by the record of past performance of the product under consideration.

(c) Mortar Colors. Mortar colors should consist of inorganic compounds, and. with the exception of carbon black, should not be used in quantities exceeding 10 to 15 per cent of the weight of the cement. The use of carbon black should be limited to 2 to 3 per cent of the weight of the cement.

(d) Admixtures. Laboratory data seem to indicate that water repellents and grinding aids increase the workability of mortars and also their resistance to weathering as determined by freezing and thawing tests on mortar bars or cubes. Such admixtures, however, have little or no effect upon the shrinkage of mortars either during or subsequent to hardening. The use of salt for lowering the freezing point and sugar for retarding set should be prohibited.

The following is quoted from the Report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete, dated June, 1940. In the author's opinion, this statement regarding admixtures for use in concrete is equally applicable to masonry mortar.

"The committee considers that the benefits to be derived from the use in concrete of other than the essential ingredients (cement, aggregates, and water) depend so much upon the conditions surrounding the individual project that it is virtually impossible to write an adequate general specification for these materials. This applies particularly to admixtures which are employed for the purpose of promoting workability. The desirability of using an admixture as well as the amount to be used depends greatly on the characteristics of the essential ingredients, especially aggregate grading, as well as on the proportions in which they are to be combined. Before permitting the use of an admixture, the engineer should inform himself thoroughly as

to the advantages or disadvantages to be derived from its use considering both quality and economy. He should determine definitely the effect of the proposed admixture on the strength, volume change, durability, and density of the concrete. The possibility of securing the desired results in other ways, such as by the use of additional cement, better aggregate gradation, closer water control during construction, etc., should be investigated. The committee recognizes that admixtures, under certain conditions, may impart desirable characteristics which cannot be secured as economically by other methods. However, it should be emphasized that the use of admixtures cannot be considered a panacea for any of the ills which result from ignoring the fundamental principles governing the making of good concrete."

(e) Aggregate. Many properties of mortar, including water retentivity, volume change and strength, are affected materially by the type and grading of aggregate, particularly the latter. Aggregate should conform to ASTM Specifications C144—.

Designers are urged to investigate the grading of sands available locally and, if such sands do not conform to the requirements of the specifications, adjust the aggregate through the addition of fine or coarse material.

CHAPTER 6

PROPERTIES OF BRICK AND TILE WALLS

601. GENERAL

The sections which follow summarize the data available on various properties of brick and tile walls affecting their performance, and include data on such properties as compressive, transverse, and other strength measures, heat transmission, sound transmission, fire resistance, resistance to rain penetration, and the adhesion of plaster and stucco to the wall surfaces.

While the properties of masonry walls are affected to a degree by the physical properties of the units, including the arrangement of cells and other design features, they may be influenced to an equal degree by other factors, such as the properties of the mortar and the workmanship, including the manner of forming the mortar joints.

For this reason, when averaging the numerical measures of any particular property, care must be exercised to ascertain that all of the values included in the average were obtained from constructions which are similar insofar as the factors that have an important effect on the properties are concerned.

Examples of improper averages, which are meaningless in that they do not represent a property of any single type of construction, are averaged compressive strengths in which the strength of both side-construction and end-construction tile walls have been included, or an average conductance coefficient which includes coefficients of walls constructed of both flat and recessed bed tile.

602. COMPRESSIVE STRENGTH

The principal factors affecting the compressive strength of brick and tile walls are compressive and other strength measures of the units, strength of mortar, workmanship and, particularly in the case of end-construction tile, the proportion of gross area given a bearing at bed joints. Other factors which affect compressive strength, possibly to a lesser degree, are thickness of the mortar joints, the regularity of the bearing surfaces of the units and the workability of the mortar.

The compressive strengths of brick and tile masonry walls are increased by high strength units and mortars, and by workmanship characterized by smooth (unfurrowed) bed joints and complete filling of head and collar joints. All other factors being equal, units most regular in size and with plane parallel faces will give highest masonry strength. Within the limitations of workability, thinner mortar joints contribute to stronger masonry.

The data are somewhat contradictory as to the effect on compressive strength of masonry of increasing or decreasing the number of header courses. Some tests indicate that highest strengths are obtained under central loading

with masonry having no headers. Headers are needed to cause common action of the vertical elements of walls under lateral loads and they assist to distribute eccentric loads, but both the results of laboratory tests and service records of structures indicate that the number required by many existing codes could be reduced substantially without having a practical effect on the strength or stability of masonry.

(a) Brick Walls. Results of tests of 168 solid and hollow brick walls are reported in National Bureau of Standards Research Paper No. 108, "Compressive Strength of Clay Brick Walls," by A. H. Stang, D. E. Parsons and J. W. McBurney. Ten types of walls were tested, including 8-in. and 12-in solid brick walls, 3 types of 8-in. rowlock and 4 types of 12-in. rowlock walls, and 4-in. economy walls. All wall specimens were 6 ft. long and approximately 9 ft. high.

These tests indicate the effect of strength of brick, type of mortar, workmanship and type of construction on brick wall strength.

Brick from 4 different sources were used in this investigation, designated in the report by the name of the region in which they were produced. They are described as follows:

Chicago brick were made from surface clay and formed by the end-cut, double-column, stiff-mud process. They are rather irregular in shape and contain lime nodules.

Detroit brick were formed by the soft-mud process from surface clay. Like many soft-mud brick, they were formed with a frog or depression in one face approximately 0.4 in. deep.

Mississippi brick were surface clay brick formed by the dry press process. Regularity of size and shape was the outstanding characteristic of these specimens.

New England brick were formed by the soft-mud process from surface clay and were "sand struck." The specimens contained a shallow frog or depression, were very hard burned, and rather irregular in size and shape.

The physical properties of these brick are given in Table 6-1. Each average value, except for shearing strength, is the result of 50 tests.

TABLE 6-1

AVERAGE PHYSICAL PROPERTIES OF THE BRICK

Kind of Brick	Absorption		Modulus of Rupture		Compressive Strength		Tensile Strength,	Shearing Strength,
	5 hr. boil, per cent	48 hr. cold, per cent	Flat-wise, psi	Edge-wise, psi	Flat-wise, psi	Edge-wise, psi	psi	psi
Chicago....	16.5	11.7	1225	1340	3280	3350	417	1100
Detroit.....	22.3	20.7	670	680	3540	3270	222	1165
Mississippi .	21.7	16.7	820	760	3410	3625	317	1590
New England	9.2	6.9	1550	1640	8600	11470	601	3550

Two mortars were used in the investigation: A cement mortar consisting of 1 part portland cement:0.10 parts lime:3 parts sand, by volume (weight equivalents: 94 lb. cement:4 lb. lime:220 lb. sand); and a cement-lime mortar

consisting of 1 part portland cement:1 part hydrated lime:6 parts sand, by volume (weight equivalents: 94 lb. cement:40 lb. lime:440 lb. sand). Compressive strengths of these mortars are given in Table 6-2.

TABLE 6-2

COMPRESSIVE STRENGTH OF MORTAR SPECIMENS

Mortar	Proportions ① (by volume)	Strength ②	
		Cured wet, psi	Cured dry, psi
Cement-lime...............	1C:1L:6S	1100	750
Cement....................	1C:1/10L:3S	3260	1950

① C=cement, L=lime, S=sand.

② Cylinders 2 in. in diameter, 4 in. long, tested at 57 to 62 days.

Two types of workmanship were used in building the test specimens. Type A, designated as "inspected", was characterized by complete filling of all mortar joints and smooth (unfurrowed) bed joints.

Type B, designated as "commercial", was characterized by deeply furrowed bed joints, partially filled head joints, and practically no mortar in the longitudinal vertical (collar) joints.

Bids were obtained for the construction of Type B walls from a number of brick masons and the work was awarded to the lowest bidder who received no instructions as to the type of workmanship which should be employed in building the specimens, other than it should be the same as would be used in commercial work.

The 8-in. and 12-in. solid walls were laid in common American bond with headers every sixth course. However, none of the solid walls had header courses at the top or bottom. The hollow walls had header courses at the top and bottom. In the all-rowlock walls, the stretchers were laid on edge.

The economy wall is essentially a 4-in. wall with pilasters 8 in. wide and 4 in. thick built into the wall at intervals of 5½ stretcher lengths (approximately 4 ft.). The pilasters were tied to the 4-in. wythe with headers every sixth course. All brick were laid flat. The economy walls of this investigation were plastered on the back between the pilasters with the same kind of mortar as that used in laying the brick, since this method of construction is recommended for weatherproofing the single wythe.

The average compressive strengths of solid and 4-in. economy brick walls as reported in Research Paper No. 108 are given in Tables 6-3 and 6-4 respectively.

To determine a basis for predicting the compressive strength of brick masonry walls from the strength of relatively small masonry test specimens, ASTM Committee C-15 appointed a Working Subcommittee on Tests for Brick Prisms in 1937. This committee formulated a program of tests which were carried out at Columbia University under the direction of Professor W. J. Krefeld, and were reported by Professor Krefeld in a paper, "Effect of Shape of Specimen on the Apparent Compressive Strength of Brick Masonry", which was appended to the 1938 Report of Committee C-15, ASTM Pro-

TABLE 6-3

AVERAGE COMPRESSIVE STRENGTH OF SOLID BRICK WALLS

Kind of Brick	Compressive strength of half brick, flatwise psi	Average Compressive Strength Solid Brick Walls (1)			
		Inspected Workmanship		Commercial Workmanship	
		Cement-lime Mortar, psi	Cement Mortar, psi	Cement-lime Mortar, psi	Cement Mortar, psi
Chicago	3280	....	895	585	660
Detroit	3540	945	1145	....	....
Mississippi	3410	1300	1550	....	870
New England	8600	1875	2855	....	2030

(1) Tested at 57 to 62 days.

TABLE 6-4

RESULTS OF COMPRESSIVE TESTS OF BRICK WALLS

Type of Wall	Inspected Workmanship					
	Mortar	Kind of Brick	Wall Strength (1), psi			
			a	b	c	Average
4" Economy	Cement-lime ..	Mississippi ...	1370	1365	1565	1435
		New England.	1960	1975	1880	1940
	Cement	Mississippi ...	1650	1350	1875	1625
		New England.	2755	3520	3160	3145

(1) Tested at 57 to 62 days.

ceedings, Vol. 38, Part I. The data included in this report indicate that the compressive strength of brick masonry is influenced by the ratio of height to thickness $\frac{h}{d}$ of the test specimen; that the "normal" strength of masonry, similar to the specimens tested, is obtained for an $\frac{h}{d}$ ratio of 6 or greater, and for smaller ratios the apparent strength is increasingly greater.

Based on the tests reported, Professor Krefeld suggests correction factors which may be used in predicting the strength of solid brick walls from the strength of small brick masonry specimens. These correction factors are given in Table 6-5.

Due to the many factors which affect the strength of solid masonry walls, wall strength can be predicted most accurately from the strengths of masonry prisms, constructed of the same workmanship and materials and with the same bonding arrangement that will be used in the construction, to which the correction factors in Table 6-5 may be applied. However, if

TABLE 6-5

STRENGTH CORRECTION FACTORS FOR BRICK MASONRY PRISMS

Ratio, Height to Thickness h/d	Strength Correction Factor	Ratio, Height to Thickness h/d	Strength Correction Factor
1.1	0.45	4.5	0.93
1.5	0.59	5.0	0.96
2.0	0.67	5.5	0.98
2.5	0.75	6.0	1.00
3.0	0.80	8.0	1.03
3.5	0.85	10.0	1.06
4.0	0.89	12.0	1.09

data are not available on the strength of masonry prisms, brick masonry wall strengths may be predicted with reasonable accuracy by the following method:

For brick walls laid up with cement mortar having a 2-in. cube compressive strength of not less than 2500 psi when cured wet for 28 days and with Type A "inspected" workmanship, wall strength will be approximately one-third of the compressive strength of brick, provided the brick strength exceeds 4500 psi. For brick having compressive strengths of 2500 psi, the wall strength will be approximately 50 per cent of the strength of the brick.

For brick strengths between 2500 and 4500 psi, the estimated wall strengths should be proportioned between 50 and 33 per cent of brick strength.

All other factors remaining constant, brick wall strength varies approximately as the cube root of mortar strength. Brick walls laid up with cement-lime mortars (1:1:6) having 2-in. cube compressive strengths of from 600 to 1200 psi, when cured wet for 28 days, and with Type A "inspected" workmanship, may be expected to have strengths of 60 to 70 per cent of the strength of similar walls built with cement mortar (1:1/4:3).

All other factors remaining constant, walls constructed with Type B "commercial" workmanship, will have strengths approximately 60 per cent of similar walls constructed with Type A "inspected" workmanship.

(b) End Construction Tile Walls. Tests conducted at the National Bureau of Standards to determine the compressive strength of structural tile walls are reported in Technologic Paper No. 238 by Herbert L. Whittemore and Bernard D. Hathcock, and Technologic Paper No. 311 by A. H. Stang, D. E. Parsons and H. D. Foster. Tests of walletts (3 ft.. by 3 ft.) are reported in Research Paper No. 37 by S. H. Ingberg, and H. D. Foster.

Technologic Paper 238 reports tests on 32 walls approximately 4 ft. long and 12 ft. high and TP311 reports tests on 70 hollow tile walls 6 ft. long and 9 ft. high. A summary of the data from these papers on compressive strength of end-construction masonry of hollow units is given in Table 6-6.

It will be noted from this table that, in general, the compressive strength of the walls reported in TP238 is greater than the values reported in TP311. This difference is attributed to the stronger mortar, higher compressive strength of units and better workmanship used in the construction of the walls in TP238 than in the walls reported in TP311.

Regarding workmanship the authors of TP238 state: "The walls built of high strength tile were set with great care by an experienced mason. They were undoubtedly much stronger than walls built under ordinary conditions"; while the authors of TP311 report: "Contract for building the walls was let

TABLE 6-6

COMPRESSIVE STRENGTH OF END-CONSTRUCTION MASONRY OF HOLLOW UNITS

Source of data	Wall thickness, in.	Type of units and size, in.	Mortar		Estimated ratio of bearing area to gross area	Compressive Strength of Units		Compressive strength of masonry (gross area), psi
			Mixture by Volume ①	Compressive strength, psi		Gross area, psi	Net area, psi	
TP 238	12	XXX②, 12x12x12	1C:¼L:3S	2,150	.41	2,850	6,930	933
TP 238	6	XXX, 6x12x12	1C:¼L:3S	2,150	.47	4,020	8,520	1,020
TP 238	8	XXX, 8x12x12	1C:¼L:3S	2,150	.46	2,320	5,010	1,040
TP 238	12	XXX, 12x12x12	1C:¼L:3S	2,150	.45	1,680	3,770	930
TP 238	6	XXX, 6x12x12	1C:¼L:3S	2,150	.53	1,900	3,610	690
TP 311	8	6-cell, 8x12x12	1¼L:3S	85	.19	1,830	4,470	90
TP 311	8	6-cell, 8x12x12	1C:1¼L:6S	760	.19	1,830	4,470	275
TP 311	8	6-cell, 8x12x12	1C:1¼L:6S	760	.23	1,270	2,740	295
TP 311	8	XXX, 8x12x12	1C:1¼L:6S	760	.34	2,100	4,260	370
TP 311	12	6-cell, 12x12x12	1C:1¼L:6S	760	.25	1,860	4,940	335
TP 311	8	6-cell, 8x12x12	1C:1¼L:4S	1,190	.26	1,830	4,470	460
TP 311	8	6-cell, 8x12x12	1C:1¼L:4S	1,190	.28	2,840	6,470	550
TP 311	8	XXX, 8x12x12	1C:1¼L:4S	1,190	.49	2,100	4,260	650
TP 311	8	XXX, 8x12x12	1C:1¼L:4S	1,190	.39	2,030	5,280	610
TP 311	8	Double shell, 8x12x5	1C:1¼L:4S	1,190	.30	3,320	6,900	555
TP 311	8	6-cell, 8x12x12	1C:3S	1,990	.19	1,830	4,470	355

① C=cement, L=lime and S=sand.

② Four cell, double center cross web tile.

on a lump-sum basis to a contractor whose workmen were experienced in hollow tile construction.****They were instructed to build the walls in the same manner and with the same care that they would use on a commercial job. No other instructions in regard to workmanship were given them."

Based on the data included in Table 6-6 and data reported by Talbot and Abrams in University of Illinois Bulletin No. 27 on the compressive strength of "terra cotta block columns" built of units cored approximately 25 per cent, now designated as solid masonry units, D. E. Parsons has developed a formula for estimating the probable compressive strength of concentrically loaded masonry walls constructed of end-construction hollow units.

This formula is:

$$M = b\sqrt{mu} \quad \ldots\ldots (1)$$

Where M = compressive strength of the masonry in psi.
b = ratio of bearing area in masonry to gross area.
m = compressive strength of mortar specimens in psi.
u = compressive strength (gross area) of units in psi.

The bearing area in masonry used in determining the value of "b" in formula (1) is the area of the tile unit covered with mortar on which the shells or webs of the units in the course above have bearing. In many types of end-construction tile, this area consists only of the area of the outer and inner face shells of the unit.

Factors considered in developing formula (1) and the method of derivation are outlined in National Bureau of Standards Research Paper No. 310, "Factors Affecting the Strength of Masonry of Hollow Units," by D. E. Parsons.

(c) Side-Construction Tile Walls. Table 6-7 summarizes the data from TP238 and TP311 on compressive strength of side-construction masonry of hollow units.

Commenting on these data, Mr. Parsons states in Research Paper No. 310:

"The available data relating to side-construction masonry are inadequate for the determination of an equation for computing probable masonry strength.

"Without having some way for evaluating the effects of workmanship, direct comparisons to determine the relations between wall strength and properties of the mortars are not easily made. About the only general statement warranted is that the use of stronger mortars usually result in stronger masonry.

"Insofar as the units are concerned, the data indicate that the three following properties have an important effect on the strength of masonry: (1) compressive strength, (2) ratio of thickness of bearing shells to maximum span between vertical supports, (shells and webs) and (3) features of design affecting the proportion of area given a bearing at bed joints."

Summarizing the data reported in TP311, the authors state: "The average strength of each set of side-construction walls built of tile having a compressive strength of more than 500 psi. and with 1:1¼:4 (cement-lime-sand by volume) mortar were in all cases greater than 330 psi. The average strengths of each set of end-construction walls built with 1:1¼:4 (cement-lime-sand by volume) mortar were in all cases greater than 450 psi."

Technologic Paper 311 also included tests on walls to which the load was applied with an eccentricity of 2 in. Regarding these walls, the authors state:

TABLE 6-7

COMPRESSIVE STRENGTH OF SIDE-CONSTRUCTION MASONRY OF HOLLOW UNITS

Source of data	Wall thickness, in.	Type of units and size, in.	Mortar		Compressive Strength of Units		Compressive strength of masonry (gross area), psi
			Mixture by Volume ①	Compressive strength, psi	Gross area, psi	Net area, psi	
TP 238	12	XXX②, 12x12x12	IC:¼L:3S	2,150	840	3,780	375
TP 238	8	XXX, 8x12x12	IC:¼L:3S	2,150	1,240	5,460	395
TP 238	6	XXX, 6x12x12	IC:¼L:3S	2,150	1,665	5,930	700
TP 238	6	XXX, 6x12x12	IC:¼L:3S	2,150	585	1,870	380
TP 311	8	6-cell, 8x12x12	1¼L:3S	85	500	2,210	165
TP 311	8	6-cell, 8x12x12	1C:1¼L:6S	760	500	2,210	285
TP 311	8	H-shaped, 8x10¼x12	1C:1¼L:6S	760	1,040	3,350	455
TP 311	12	6-cell, 12x12x12	1C:1¼L:6S	760	580	2,620	385
TP 311	8	6-cell, 8x12x12	1C:1¼L:4S	1,190	500	2,210	405
TP 311	8	6-cell, 8x12x12	1C:1¼L:4S	1,190	330	1,290	230
TP 311	8	6-cell, 8x12x12	1C:1¼L:4S	1,190	1,740	7,080	500
TP 311	8	XXX, 8x12x12	1C:1¼L:4S	1,190	430	1.500	240
TP 311	8	2-cell, 8x5x12	1C:1¼L:4S	1,190	820	3,740	335
TP 311	8	3-cell, 8x5x12	1C:1¼L:4S	1,190	900	3,540	440
TP 311	8	T-shaped, 8x6¼x12	1C:1¼L:4S	1,190	340	1,150	305
TP 311	8	T-shaped, 8x6¼x12	1C:1¼L:4S	1,190	630	1,870	430
TP 311	8	T-shaped, 8x6¼x12	1C:1¼L:4S	1,190	340	1,150	340
③	8	Cube, 8x8x8	1C:1¼L:4S	1,190	780	3,060	430
TP 311	8	6-cell, 8x12x12	1C:3S	1,990	500	2,210	360

① C=cement, L=lime and S=sand.
② Four cell, double center cross web tile.
③ Unpublished data.

"On the average, the loads supported by the eccentrically loaded walls were 60 per cent as great as those supported by similar walls centrally loaded."

(d) Brick and Tile Walls. Results of compressive tests on six 12-in. brick and tile walls are reported in National Bureau of Standards Research Paper RP972 by D. E. Parsons and David Watstein. Fig. 6-1 is a view of five of these walls and Fig. 6-2 shows the design of the structural tile used in their construction. The walls were 9 ft. 3 in. high, 5 ft. 1 in. long, and 12.3 in. thick. A cement-lime mortar was used consisting of 1 part cement, 1 part lime and 6 parts sand by volume. The compressive load was applied with an eccentricity of 1.15 in. and the walls were tested at ages of 57 to 62 days.

Table 6-8 gives the compressive strength of these walls from which it will be noted that the strength of the walls backed up with tile having shell thicknesses of ¾ in. are of the same order as the strengths reported in Table 6-3, while the strengths of the walls backed up with tile of thicker shells increased as the shell thicknesses increased.

TABLE 6-8

COMPRESSIVE STRENGTH OF BRICK AND TILE WALLS

Designation of wall	Tile			Weight of walls per unit of face area, psf	Compressive strength,① psi
	Unit Designation	Description	Thickness of face shells, in.		
A-1	A	6-cell, 8x12x7½	0.75	88	235②
A-2	A	(standard)	.75	88	320
Average					280
B-1	B	6-cell, 8x12x7½	1.50	100	655
B-2	B	(thick shells)	1.50	100	590
Average					620
C-1	C	Double shell, 8x12x7½	1.12	92	335③ or 480
C-2	C		1.12	92	450
Average					390③ or 465

① The compressive strength was calculated as the maximum load supported by the wall divided by the gross cross-sectional area of the wall.

② The upper 2 courses of wall A-1 were not well bedded and fragments of tile and brick were found, after the test, in the joints of these courses.

③ The first failure of wall C-1 appeared to be premature and to be caused by defective construction in the upper 2 courses of tile. These courses failed at 335 psi. After removing these courses, the wall was retested and supported 480 psi before failure.

(e) Pilasters. The strength of structural clay tile and composite brick and tile pilasters when subjected to a load comparable to that imposed by a horizontal beam or girder was investigated at Ohio State University by J. R. Shank and H. D. Foster and the results are reported in Engineering Experiment Station Bulletin No. 57, "Strength of Brick and Tile Pilasters Under Varied Eccentric Loadings."

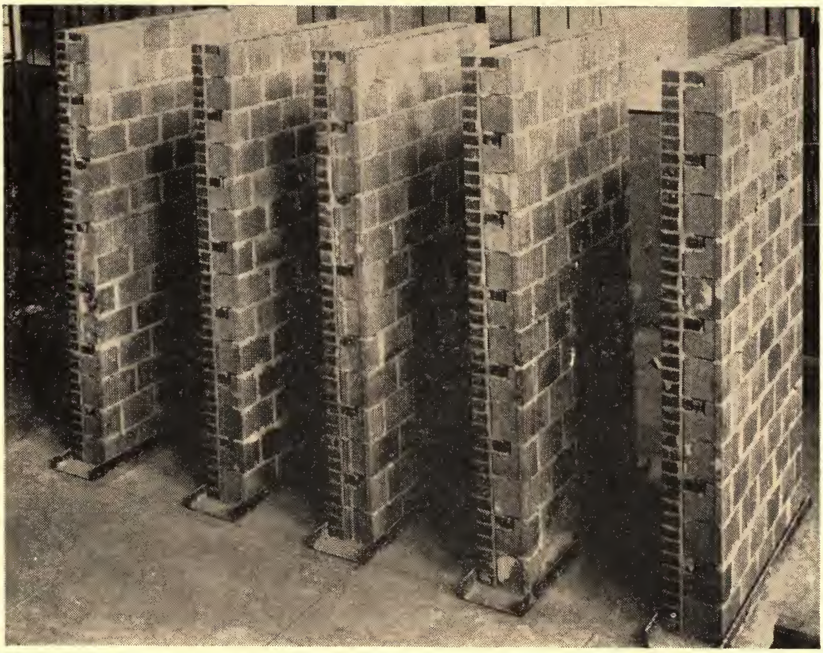


FIG. 6-1

View of five walls for compression tests

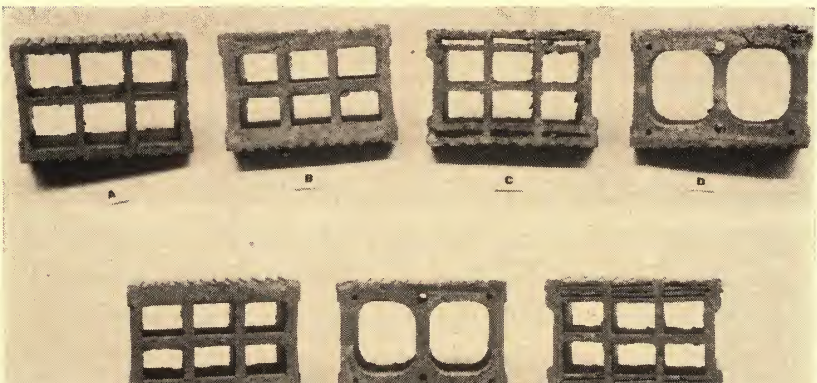


FIG. 6-2

Structural clay tile units used in test panels

TABLE 6-9

COMPRESSIVE STRENGTH AND ABSORPTION OF MATERIALS USED IN PILASTERS

Source	Clay	Nominal size, in.①	Average weight, lbs.	Average absorption, per cent	Position in test	Average ② area under load, gross sq. in.	Average compressive strength, gross area psi
1	Fire Clay	8x5x12	15.2	11.20	Side	94.8	1403
		3¾x5x12	8.3	10.77	Side	45.8	1075
		8x12x5	14.2	10.96	End	95.3	2487
		3¾x12x5 ...	7.6	9.97	End	44.8	4156
2	Fire Clay	8x8x8	19.0	5.42	End	60.3	4955
		8x8x8	19.0	3.76	Side	59.4	1867
		3¾x8x8	9.3	5.35	End	28.8	4800
		3¾x8x8	9.3	3.92	Side	28.0	1499
		Header Cubes	16.8	4.17	Side	28.0	2140
3	Fire Clay	8x8x8	16.2	10.63	End	59.5	2802
		8x8x8	16.1	9.38	Side	54.8	880
		3¾x8x8	8.4	5.90	End	29.2	3829
		3¾x8x8	8.4	7.11	Side	29.5	1463
		Header Cubes	14.2	7.75	Side	29.5	1193
4	Shale	8x3½x12	14.2	4.42	Side	90.8	1606
		3¾x3½x12 ..	8.8	6.25	Side	44.5	4853
		3½x8x3½ ...	5.5	4.02	End	26.9	11583
		3½x10x3½ ..	6.5	3.75	End	33.1	10233
5	Shale	8x12x5	19.6	11.10	End	98.0	5102
		4x12x5	13.2	7.03	End	47.9	8153
6	Fire Clay	8x5x12	17.3	5.32	Side	93.6	2193
		8x5x8	11.6	5.34	Side	62.1	2301
		4x5x8	6.5	6.91	Side	30.9	1928
		4x8x5	7.5	4.40	End	28.9	9220
7	Fire Clay	12x12x12	56.8	4.41	End	143.4	3341
		8x12x12	42.0	4.81	End	96.6	3536
		6x12x12	34.3	5.00	End	71.6	4395
8	Brick	3¾x8x2¼ ...	4.65	23.62	Flat	33.5	2336

① The first dimension given represents thickness; the second, width; the third, length. See American Society for Testing Materials Standard Definitions of Terms Relating to Structural Clay Tile (C43-).

② All averages are taken from the results of five tests except for the brick for which ten tests were made.

Three heights of pilasters (short, medium and long) were tested which are described in the report as follows:

S = 12 x 16-in. pilaster (4.-in. projection) built into an 8-in. wall with the limiting height of 10 ft. and a wing wall length of 8 in.
M = 16 x 16-in. pilaster (4-in. projection) built into a 12-in. wall with the limiting height of 14 ft. and a wing wall length of 8 in.
L = 20 x 24-in. pilaster (8-in. projection) built into a 12-in. wall with a limiting height of 17 ft. and a wing wall length of 12 in.

Data on the physical properties and size of the tile units are given in Table 6-9. Mortar used for the construction of the pilasters was composed of 1 part high-early-strength cement, 1 part lime and 4 parts sand by volume and the pilasters were tested at the age of 7 days. The method of test is described by the authors as follows:

"The actual testing of a pier consisted of the successive application of nine increments of loading, each of which was followed by a corresponding increment of slope of the special loading device until the working load and a slope of 0.00889 were reached. Working loads of 90 psi for hollow construction and 150 psi for solid construction were used. This slope, 0.00889, is that of the elastic line at the reaction of a simple beam uniformly loaded to produce a maximum deflection of 1 in 360. After the working load and

TABLE 6-10

RESULTS OF COMPRESSIVE TESTS OF PILASTERS UNDER VARIED ECCENTRIC LOAD

Pilaster designation	Modulus of elasticity, psi	Ultimate total, lb.	Strength Unit, psi	Deflection in 10 ft. of height	
				at design① load, in.	at 80 per cent ultimate load, in.
1-S-F	1,080,000	112,800	587	0.0275	0.0715
1-S-UF	1,077,000	104,000	542	0.0250	0.0700
2-S-UF	1,950,000	154,500	805	0.0100	0.0530
4-S-UF	2,730,000	178,150	929	0.0350	0.0706
5-S-UF	1,420,000	178,400	930	0.0175	0.0760
8-S-F	292,000	154,000	802	0.0775	0.1507
1-M-F	715,000	147,350	576	0.0303	0.0511
1-M-UF	595,000	132,050	516	0.0268	0.0977
2-M-F	3,220,000	136,875	534	0.0214	0.0780
3-M-F	1,075,000	125,150	489	0.0125	0.0364
6-M-F	1,550,000	130,550	510	0.0143	0.0399
8-M-F	658,000	237,800	928	0.0768	0.0978
1-L-F	1,620,000	210,800	660	0.0172	0.0583
2-L-F②	2,260,000	246,500	770	0.0077	0.0724
7-L-UF②	1,900,000	240,900	753	0.0187	0.1275
8-L-F	303,000	275,100	860	0.0391	0.1400

① A design load of 90 psi was used for hollow construction and 150 psi for solid construction.

② A mortar consisting of one part Incor cement by volume to three parts of sand and tempered with 15 per cent of lime was used for these two pilasters.

the desired slope were reached, further increments of load were successively applied but this slope was maintained until failure occurred.

"Deformation and deflection readings were taken initially and after the application of each increment of loading. An accurate description of cracking and other damage to the pier was also made."

Table 6-10 shows the results of these tests. The pilaster designation listed in column (1) indicates the type of the pilaster and the material used in its construction. The first number in the notation refers to the material which may be identified by referring to Table 6-9.

The letter following this number indicates the type (short, medium or long) and the following letters indicate whether or not the pier was faced with brick. The single letter "F" designates pilasters faced with brick while the letters "UF" designate unfaced or all-tile pilasters.

Regarding these tests the authors conclude:

"Structural clay tile of 'medium or better grade' under properly limited working loads (90 psi) gave a factor of safety of approximately 6 and would be a safe material for use in all portions of load-bearing walls.

"The lateral deflection was in no case large enough to be considered serious.

"The tests did not indicate a lowering of the strength by the use of nailing plugs."

603. TRANSVERSE STRENGTH

The transverse strength or resistance to lateral forces of brick and tile walls depends primarily upon the type of masonry unit, the strength of the mortar, and workmanship. Other factors affecting transverse strength are water retentivity, consistency of the mortar when used, and the design of the unit which affects the width of the mortar bed at right angles to the face of the wall.

Higher transverse strengths are associated with brick and side-construction tile; suction rate of unit when laid of 20 grams per 30 sq. in. per min. or under; mortars of high strength, high water retentivity and high workability, the latter obtained by the use of the maximum water consistent with workability; and Type A workmanship, characterized by full mortar joints and flat or only slightly furrowed bed joints.

Since failure of brick and tile walls subjected to transverse loads is usually at a horizontal bed joint and results from failure of the bond between mortar and brick or tile, factors which increase tensile bond strength may be expected also to increase the transverse strength of brick and tile walls. Most important of such factors are high mortar strength, low suction rate (0.7 oz. or under) of unit when laid, maximum water content of mortar consistent with workability, smooth (unfurrowed) mortar joints, and the application of pressure to the mortar joints during and immediately after forming.

Lateral stability of brick and tile walls is increased by superimposed loads which produce compressive stresses that must be counteracted by tensile stresses created by transverse forces before resultant tensile stresses are induced in the masonry. The addition of steel reinforcement greatly increases the lateral strength of masonry walls.

(a) Brick Walls. Numerous tests have been conducted to determine the lateral strength (modulus of rupture) of solid brick masonry walls. As a rule, walls 4 to 6 ft. long and from 8 to 12 ft. high were tested in a vertical

position by rigidly supporting the specimen at top and bottom, and applying transverse loads at the third points of the span.

Data reported in National Bureau of Standards Report BMS5 on three solid brick walls, designated as AA, AB, and AC, are typical of the results of such tests. Tables 6-11 and 6-12 give the physical properties of the brick and mortar used for the construction of these walls, and Table 6-13 summarizes the results of the transverse tests.

TABLE 6-11

PHYSICAL PROPERTIES OF BRICK

Brick	Compressive strength, psi	Modulus of rupture, psi	Water absorption					Weight, dry ① lb.
			24-hr. cold, C per cent	5-hr. boil, B per cent	Ratio C/B	1-min. partial immersion ①		
						Dry	As laid	
High-strength ...	17,600	2,275	1.9	3.45	0.53	8	8	5.85
Medium-strength ..	2,670	550	11.3	15.1	0.74	23	11	4.49

① Immersed on flat side in ⅛ in. of water. Absorption in grams per brick.

TABLE 6-12

PHYSICAL PROPERTIES OF MORTAR

Kind of Mortar	Proportion, by volume	Water content, by weight of dry materials, per cent	Flow, per cent	Compressive strength	
				Air Storage, psi	Water Storage, psi
Cement	1C:0.25L:3S	19.6	113	1390	3220
Cement-lime ...	1C:1L:6S	23.3	107	440	640

C=cement, L=lime and S=sand.

Test specimens AA were built with high strength brick laid in common American bond with headers every sixth course and cement mortar. All joints were completely filled with mortar. The bed joints were flat. The head and collar joints were filled by buttering heavily the ends of brick laid in the facing and both the ends and sides of brick laid in the backing. The mortar was applied to the brick by scraping the trowel against the lower edges and unfilled portions of the joints were filled by slushing mortar from above. The joints were cut flush with the face of the specimen. This is the type of workmanship characterized as Type A in Section 602(a).

Test specimens AB were built with medium strength brick laid in common American bond with headers every sixth course and cement-lime mortar. The joints were not completely filled with mortar. The bed joints were furrowed;

collar joints were left open, and only the outside of the head joints was filled by lightly buttering the outer edges of the brick. The joints were cut flush with the face of the specimen. This is the type of workmanship characterized as Type B in Section 602(a).

Test specimens AC were built with medium strength brick laid in common American bond with headers every sixth course and cement-lime mortar. The workmanship was Type A, the same as used for test specimens AA.

TABLE 6-13

TRANSVERSE TESTS ON BRICK WALLS

Wall Type	Equivalent Uniform Load, psf				Modulus of Rupture ①, psi			
	1	2	3	Average	1	2	3	Average
AA	115	120	140	125	73.6	76.7	89.5	79.9
AB	53.3	38.0	52.3	48	34.7	24.7	34.0	31.1
AC	85	80	82	82	53.6	50.4	51.7	51.9

① Tested at age of 28 days.

While the data from these tests are not sufficient to warrant generalizations, it is interesting to note that the average transverse strength of walls AC is approximately 70 per cent of the strength of walls AA where the principal variable affecting transverse strength is the strength of the mortar. This is the same percentage suggested in Section 602(a) for estimating the difference in compressive strength of walls similar in all respects except the mortar.

In like manner, it will be noted that the average transverse strength of walls AB is approximately 60 per cent of the strength of walls AC which is the same percentage suggested for estimating the difference in compressive strength of walls constructed of Type A and Type B workmanship.

Flexure tests, reported by Professor Raymond E. Davis of the University of California on wall specimens which had been loaded with an increasing load each day for the first 20 days after construction, in order to simulate the increasing load of brickwork upon the lower portions of a brick building, indicate the modulus of rupture of masonry thus loaded is approximately 40 per cent greater than of similar specimens not loaded.

These wall specimens were tested as beams at the ages of 2 months, 6 months and 12 months, and the specimens were subjected to the total load superimposed at the end of 20 days until just before testing.

(b) Structural Tile Walls. Tests of the transverse strength of 27 structural tile walls, 9 ft. high and 6 ft. long, are reported in National Bureau of Standards Technologic Paper No. 311. These walls were tested in a vertical position by restraining the top and bottom against lateral movement and applying loads at right angles to the face of the wall at the third points of the span between the restraints. Results of these tests of end-construction and side-construction walls are given in Tables 6-14 and 6-15, respectively.

The average strengths of the mortars used in constructing the walls listed in these tables are given in Table 6-16.

TABLE 6-14

RESULTS OF TRANSVERSE TESTS OF END-CONSTRUCTION HOLLOW TILE WALLS

Wall thickness, in.	Description of tile and size, in.	Mortar Proportion by Volume	Maximum load, lb.	Distance Between Restraints, in.	Equivalent uniform load, psf	Modulus of rupture, psi
8	6-cell, 8x12x12	1¼L:3S	1,080	106	27	18
8	6-cell, 8x12x12	1C:1¼L:6S	2,080	107	52	41
8	6-cell, 8x12x12	1C:1¼L:6S	2,390	105	60	47
8	6-cell, 8x12x12	1C:1¼L:4S	1,670	107	41	32
8	6-cell, 8x12x12	1C:1¼L:4S	1,980	102	50	36
8	XXX,① 8x12x12 ...	1C:1¼L:4S	1,980	107	49	39
8	XXX, 8x12x12	1C:1¼L:4S	2,190	104	55	41
8	Double shell, 8x12x5	1C:1¼L:4S	3,320	107	82	70
8	6-cell, 8x12x12	1C:3S	2,660	106	66	53
12	6-cell, 12x12x12 ...	1C:1¼L:6S	5,580	105	140	49
12	6-cell, 8x12x12 ..... 3-cell, 3¾x12x12 ...	1C:1¼L:6S	5,690	106	142	50

① Four cell, double center cross web tile.

TABLE 6-15

RESULTS OF TRANSVERSE TESTS OF SIDE-CONSTRUCTION HOLLOW TILE WALL

Wall thickness, in.	Description of tile and size, in.	Mortar Proportion by Volume	Maximum load, lb.	Distance Between Restraints, in.	Equivalent uniform load, psf	Modulus of rupture, psi
8	6-cell, 8x12x12	1¼L:3S	1,970	108	49	39
8	6-cell, 8x12x12	1C:1¼L:6S	2,900	109	71	62
8	H-shaped, 8x10¼x12	1C:1¼L:6S	4,350	92	115	73
8	6-cell, 8x12x12	1C:1¼L:4S	2,700	109	66	57
8	6-cell, 8x12x12	1C:1¼L:4S	2,080	110	51	44
8	6-cell, 8x12x12	1C:1¼L:4S	1,980	105	50	38
8	XXX,① 8x12x12 ...	1C:1¼L:4S	2,410	105	60	47
8	2-cell, 8x5x12	1C:1¼L:4S	3,010	104	76	60
8	3-cell, 8x5x12	1C:1¼L:4S	3,630	103	92	72
8	T-shaped, 8x6¼x12.	1C:1¼L:4S	1,980	106	49	38
8	T-shaped, 8x6¼x12.	1C:1¼L:4S	2,500	108	62	52
8	6-cell, 8x12x12	1C:3S	4,450	109	110	98
12	6-cell, 12x12x12 ...	1C:1¼L:6S	6,100	108	151	57
12	Faced with brick ...	1C:1¼L:4S	6,100	106	152	55
12	T-shaped, 8x6¼x12.	1C:1¼L:4S	4,870	106	121	42

① Four cell, double center cross web tile.

Values of modulus of rupture listed in Tables 6-14 and 6-15 were computed by taking into account the axial vertical loads on the walls of 5 psi plus the weight of the wall above the fracture line. The beam section was considered to be a solid rectangle of width equal to the length of the wall (72 in.) and of a depth equal to the thickness of the wall (8 or 12 in.).

This is of course, an arbitrary assumption since the section modulus is variable, depending upon the location of the section considered. However, it may be used in comparing the relative strengths of structural tile walls.

TABLE 6-16

AVERAGE STRENGTH OF MORTAR SPECIMENS

Mortar number	Proportions (by volume) ①	Specimens tested	Average compressive strength psi	Average tensile strength, psi
1	1¼L:3S	12	85	14
2	1C:1¼L:6S	81	760	80
3	1C:1¼L:4S	105	1,190	135
4	1C:3S	12	1,990	155

① C = cement, L = lime, S = sand.

TABLE 6-17

DATA ON MODULUS OF RUPTURE OF MASONRY WALLS

Masonry Units	Workmanship	Compressive strength of mortar, psi	Modulus of rupture of masonry, psi	No. of walls tested	Source of Data
Brick	Superior	3500	76	3	①NBS 1928
Brick	Superior	3220	80	3	NBS BMS5
Brick	Superior	2430	150	12	R. E. Davis, 1933
Brick	Superior	1700	137	12	R. E. Davis, 1933
Brick	Superior	1590	111	12	R. E. Davis, 1933
Brick	Superior	1170	50	1	Bul. 251, U. of Ill.
Brick	Superior	640	52	3	NBS BMS5
Brick	Ordinary	1580	38	1	Bul. 251, U. of Ill.
Brick	Ordinary	640	31	3	NBS BMS5
Tile-side	Superior	1200	51	10	NBS TP 311
Tile-side	Superior	645	42	3	NBS BMS5
Tile-side	Ordinary	1990	98	1	NBS TP 311
Tile-side	Ordinary	760	64	3	NBS TP 311
Tile-end	Superior	1200	44	5	NBS TP 311
Tile-end	Superior	630	25	3	NBS BMS5
Tile-end	Ordinary	1990	53	1	NBS TP 311
Tile-end	Ordinary	760	47	4	NBS TP 311
Concrete block	Superior	1870	27	3	Bul. 251, U. of Ill.
Concrete block	Superior	1330	35	2	Bul. 251, U. of Ill.
Concrete block	Superior	1130	30	4	Bul. 251, U. of Ill.
Concrete block	Superior	1100	28	11	Bul. 251, U. of Ill.
Concrete block	Superior	1040	40	2	Bul. 251, U. of Ill.
Concrete block	Superior	630	24	3	NBS BMS5

① NBS—National Bureau of Standards.

Table 6-17 summarizes data on modulus of rupture of various types of masonry walls obtained from TP311 and other sources indicated.

The variation in the values of modulus of rupture of masonry walls reported by different investigators is probably due to differences in workmanship. Workmanship, designated as "ordinary" by one investigator, might be termed "superior" by another or vice versa.

As previously indicated, the application of pressure to the mortar joint during and immediately after forming will substantially increase tensile bond strength and, as a result, the transverse strength of the masonry, and it is probable that variations in this factor which are not indicated in Table 6-17 may also account for some of the variation in reported strengths.

604. MISCELLANEOUS STRENGTH MEASURES

Few laboratory data are available on the shearing strength of brick and tile walls or their resistance to impact or concentrated loads. However, in the series of tests of building materials and structures, conducted by the National Bureau of Standards during the period 1938 until the fall of 1941, test procedures were developed for racking, impact and concentrated load tests; the data from which indicate the performance of walls subject to loads comparable to those applied in the tests. Subsequently, similar procedures have been adopted by the American Society for Testing Materials as Tentative Methods of Conducting Strength Tests of Panels for Building Construction, E72—.

Table 6-18, reproduced from Report BMS5, "Structural Properties of Six Masonry Wall Constructions", gives the results of compressive, transverse, concentrated, impact and racking tests on six masonry walls.

Two types of mortar were used in the construction of these walls: cement mortar consisting of 1 part portland cement, 0.25 part hydrated lime and 3 parts sand, by volume; and cement-lime mortar consisting of 1 part portland cement, 1 part hydrated lime and 6 parts sand, by volume.

The average compressive strength of 2-in. cubes of the cement mortar was 1390 when cured in air and 3220 psi when cured in water; and of the cement-lime mortar, 470 psi when cured in air and 635 psi when cured in water. All cubes were tested at the age of 28 days.

Two types of workmanship were used in the construction of the walls: Type A which was characterized by complete filling of all mortar joints and, in the brick and side construction tile walls, flat unfurrowed bed joints; Type B which was characterized by deeply furrowed bed joints, partially filled head joints and open (unfilled) collar joints.

Two types of brick were used for the construction of the brick walls, and the tile used for the construction of the tile walls were 6-cell, 8x12x12-in. load-bearing tile, scored on four sides.

Physical properties of the various units are given in Table 6-19.

(a) Shear. The walls tested in the shear or racking test were 8 ft. long and 8 ft. high. In conducting the test, these walls were restrained as in Fig. 6-3, and a horizontal force was applied to the edge of the wall as indicated.

The horizontal shear in psi, listed in Table 6-18, is obtained by assuming the wall to be homogeneous and by dividing the maximum horizontal force by the area of the horizontal section of the wall.

TABLE 6-18

STRUCTURAL PROPERTIES OF MASONRY WALL CONSTRUCTIONS ①

WALL MATERIAL	Weight, psf face area	Wall No.	Maximum loads: Compressive ② kips/ft.⑥	Trans-verse,③ psf	Concen-trated lb.	Impact,⑤ Maximum height of drop, ft.	Racking, kips/ft.⑥	Horizontal shear, psi
AA High Strength Brick, Type A Workmanship, Cement Mortar	96.0	AA1	249	115	1,000	7.5	6.25	64.2
		AA2	378	120	1,000	5.5	6.25	64.2
		AA3	344	140	1,000	6.5	6.25	64.2
			324 (3330 psi)	125	1,000 ④	6.5	6.25 ④	64.2 ④
AB Medium Strength Brick, Type B Workmanship, Cement-Lime Mortar	73.9	AB1	63.2	53.3	1,000	3.0	6.25	64.2
		AB2	52.5	38.0	1,000	3.0	6.25	64.2
		AB3	65.8	52.3	1,000	2.5	6.25	64.2
			60.5 (625 psi)	47.9	1,000 ④	2.8	6.25 ④	64.2 ④
AC Medium Strength Brick, Type A Workmanship, Cement-Lime Mortar	78.9	AC1	90.5	85.0	1,000	4.0	6.25	64.2
		AC2	110.0	80.0	1,000	3.5	6.25	64.2
		AC3	102.5	81.7	1,000	3.5	....	....
			101.0 (1040 psi)	82.2	1,000 ④	3.7	6.25 ④	64.2 ④
AD Structural Clay Tile, End-Construction, Type A Workmanship, Cement-Lime Mortar	42.6	AD1	49.1	41.3	1,000	1.0	4.01	41.4
		AD2	51.2	35.0	1,000	1.0	3.56	36.8
		AD3	45.0	39.8	1,000	1.5	4.50	46.5
			48.4 (503 psi)	38.7	1,000 ④	1.2	4.02	41.6
AE Structural Clay Tile, Side-Construction, Type A Workmanship, Cement-Lime Mortar	38.9	AE1	23.7	58.0	1,000	2.5	4.25	44.3
		AE2	27.5	76.8	1,000	1.5	3.56	37.1
		AE3	27.9	56.8	1,000	1.5	3.42	35.6
			26.4 (275 psi)	63.9	1,000 ④	1.8	3.74	39.0
AF Stone Concrete Block, Type A Workmanship, Cement-Lime Mortar	54.5	AF1	41.2	29.6	1,000	1.5	3.49	37.3
		AF2	38.8	36.7	1,000	1.5	3.05	32.6
		AF3	38.2	36.7	1,000	1.0	3.00	32.0
			39.4 (420 psi)	34.3	1,000 ④	1.3	3.18	34.0

① For method of testing walls, see National Bureau of Standards' Building Materials and Structures Report BMS2.
② Load applied at one-third the thickness of the specimen from the inside face.
③ Span 7 ft. 6 in.
④ Specimens did not fail.
⑤ 60 lb. sack of sand.
⑥ Kip/ft. is 1000 lb. per ft. of width of wall; 4 ft. for compressive and 8 ft. for racking specimens.

(b) Concentrated loads. The concentrated load test was performed by applying a force to the surface of the wall through a steel disc having a diameter of 1 in. and the lower edge rounded to a radius of 0.05 in. This disc "is placed on the upper face of the specimen at what is judged to be the weakest place."

Since the tile units to which the concentrated load was applied were scored, the thickness of the shells varied from a minimum of ½ in. to a maximum of ¾ in., making the area of tile subject to punching shear indeterminate between the values of 1.57 sq. in. and 2.36 sq. in.

As indicated in Table 6-18, the walls did not fail under concentrated loads of 1000 lb., which produced punching shear stresses from 424 to 636 psi. Previous tests have demonstrated that dense structural clay tile will withstand forces producing punching shear stresses of approximately 1170 psi.

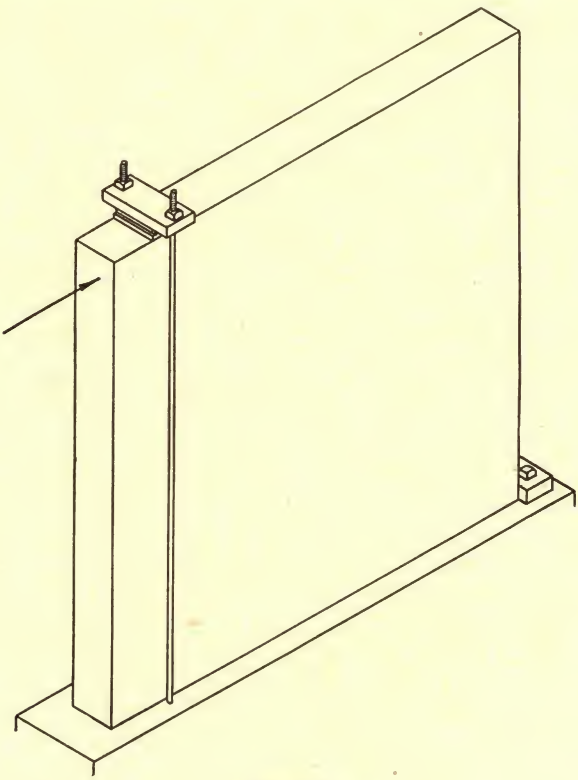


FIG. 6-3

Racking load on wall specimen

(c) Impact. Walls subjected to the impact test were 4 ft. long and 8 ft. high. This test consisted of restraining the walls against lateral movement by rigid supports at top and bottom, spaced 7 ft. 6 in. apart, and subjecting the wall to the impact of a sand bag weighing 60 lb., swinging as a pendulum from various heights and striking the center of the panel. The height at which

TABLE 6-19

PHYSICAL PROPERTIES OF WALL UNITS

Type of Material	Face shell thickness, in.	Face size dimensions, in.	Weight per unit, lb.	Compressive strength			Water absorption		
				End		Side			
				Net area, psi	Gross area, psi	Gross area, psi	24-hr. cold per cent	5-hr. boil per cent	1-hr. boil per cent
Brick, High strength............	....	$2\frac{5}{16}$x$8\frac{1}{8}$	5.85	....	....	17,600	1.9	3.45	...
Brick, Medium strength..........	....	$2\frac{1}{4}$x$8\frac{1}{16}$	4.49	....	....	2,670	11.3	15.1	...
Structural tile, End-construction..	0.50	$12\frac{1}{8}$x$12\frac{1}{16}$	35.4	9,510	3,540	.....	3.9	....	5.6
Structural tile, Side-construction.	0.50	$12\frac{1}{16}$x$12\frac{1}{8}$	35.4	....	....	1,590	3.9	....	5.6
Concrete block, End-construction..	1.25	$7\frac{11}{16}$x$11\frac{1}{2}$	29.4	2,050	1,190	.....	lb/cu. ft. concrete, 10.1 lb.	....	...

the panel failed in this test is the projected vertical height of the arc of the circle through which the sand bag fell before striking the panel.

605. CAVITY WALLS

The structural properties of all-brick and brick and tile cavity walls are reported in National Bureau of Standards Reports BMS23 and BMS24. The mortar used for the construction of both the all-brick and the brick and tile test walls consisted of 1 part portland cement, 1 part hydrated lime and 6 parts sand by volume. Tile used in the contruction of the brick and tile cavity walls were 4-cell, 4x5x12-in. horizontal backup units.

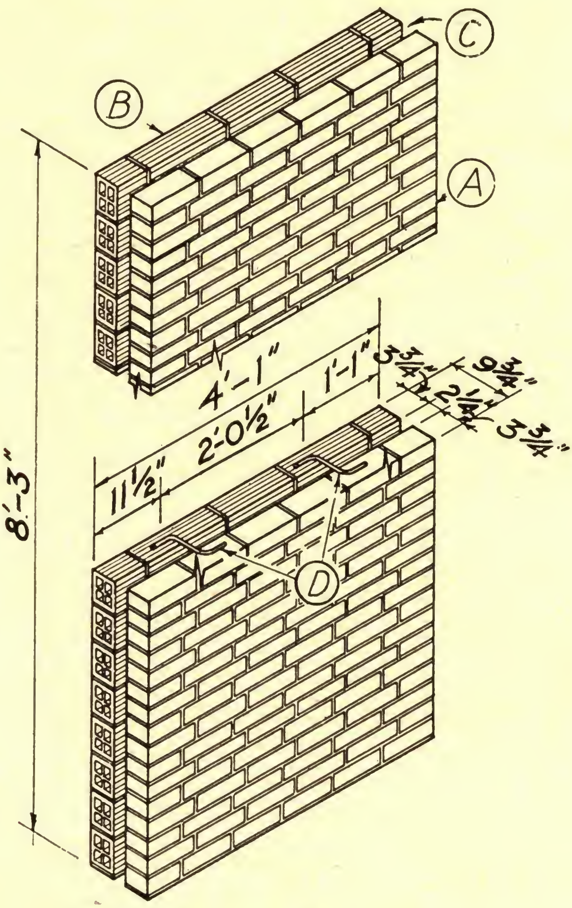


Fig. 6-4

Construction details of brick and tile cavity wall panel: A, facing; B, backing; C, air space; D, wall ties

Physical properties of the tile are given in Table 6-20 and the average compressive strengths of mortar cubes stored in water and tested on the day

the corresponding wall specimen was tested (28 days) was 732 psi for the all-brick cavity walls and 650 psi for the brick and tile cavity walls.

TABLE 6-20

PHYSICAL PROPERTIES OF THE TILE UNITS[1]

Minimum thickness		Ratio of width of cell to over-all thickness of bearing shell	Compressive strength load applied to side		Water absorption		Weight, dry, lb./tile
Unit in.	Face Shell in.		Net area, psi	Gross area, psi	24-hr. cold, per cent	1-hr. boil per cent	
$3\frac{3}{4}$	0.40	2.1	4,610	1,720	4.0	5.9	9.48

[1] Typical 4 x 5 x 12-in. backup—4-cell (side construction).

Table 6-21, reproduced from Reports BMS23 and BMS24 shows the results of compressive, transverse, concentrated, impact and racking tests on these walls. Construction details of the brick and tile cavity wall panel are shown in Fig. 6-4. The all-brick panel consisted of two wythes of brick each $3\frac{11}{16}$ in. in thickness with a 2-in. cavity between, or a total overall wall thickness of $9\frac{3}{8}$ in.

Values of modulus of rupture have not been computed from the maximum load in the transverse tests, since the performance of cavity walls subjected to transverse loads indicates that the metal ties do not have sufficient stiffness to cause the two walls to act as a single section but that the resistance of a cavity wall to lateral forces is more nearly equal to the sum of the resistances of the two wythes acting independently.

606. HEAT TRANSMISSION

National Bureau of Standards Research Paper No. 291, "Heat Transfer Through Building Walls," by M. S. Van Dusen and J. L. Fink (1931), contains the following statement regarding the flow of heat through a wall:

"The thermal resistance of the wall itself is separate and distinct from the surface resistances. It is a property of the wall and is not influenced by the surroundings except in certain cases of air leakage which will be noted later. Heat transfer through solid walls takes place only by conduction in the direction of temperature gradients. Such transfer is proportional to the temperature difference between the two surfaces of the wall and further depends on the materials composing the wall. The thermal conductivities of building materials in general increase slightly with increasing temperature; consequently the resistance of a wall will decrease somewhat with increasing mean temperature of the wall.

"Heat transfer through walls containing voids such as hollow tile, frame, or the hollow types of brick walls, takes place by convection and radiation as well as conduction. The resultant process is very complicated in any ordinary type of hollow-wall construction, and it is at present difficult to separate the three effects and ascertain which one plays the most important

TABLE 6-21
STRUCTURAL PROPERTIES OF CAVITY WALLS

Load	Load applied	Brick and Tile, Cavity Wall Weight, 62.3 psf: Specimen designation	Maximum height of drop, ft.	Maximum load
				①(Kips/ft.)
Compressive	Upper end, 3.25	C1	....	27.1
	in. from the	C2	....	26.4
	inside face	C3	....	29.8
	Average			27.8
			Gross area	(238 psi)
				(psf)
Transverse	Inside face;	T1	....	17.0
	span,	T2	....	23.8
	7 ft. 6 in.	T3	....	23.7
	Average			21.5
Transverse	Outside face;	T4	....	30.0
	span,	T5	....	26.2
	7 ft. 6 in.	T6	....	31.2
	Average			29.1
				(lb.)
Concentrated	Both faces	P1, P4	....	②1,000
		P2, P5	....	②1,000
		P3, P6	....	②1,000
	Average			②1,000
				①(Kips/ft.)
Racking	Near upper end	R1	....	5.34
		R2	....	5.11
		R3	....	5.03
	Average			5.16
Impact	Inside face;	I1	3.5	
	span,	I2	3.5	....
	7 ft. 6 in.	I3	4.0	....
	Average		3.7	....
Impact	Outside face;	I4	2.5	....
	span,	I5	3.0	....
	7 ft. 6 in.	I6	3.5	....
	Average		3.0	

Load	Load Applied	All-Brick Cavity Wall Weight, 67.6 psf: Specimen designation	Maximum height of drop, ft.	Maximum load
				①(Kips/ft.)
Compressive	Upper end, 3.12	C1	....	62.6
	in. from the	C2	....	61.7
	inside face	C3	....	61.9
	Average			62.1
			Gross area	(522 psi)
	Upper end on	C1a	....	50.9
Compressive	backing only,	C2a	....	48.3
	centered on	C3a	....	52.5
	backing			50.6
	Average		Gross area	(450 psi)
				(psf)
Transverse	One face; span	T1	....	22.0
	7 ft. 6 in.	T2	....	30.0
		T3	....	24.0
	Average			25.3
				(lb.)
Concentrated	One face	P1	....	②1,000
		P2	....	646
		P3	....	②1,000
	Average			....
				①(Kips/ft.)
Racking	Near upper end	R1	....	4.95
		R2	....	6.03
		R3	....	6.00
	Average			5.66
Impact	One face; span	I1	3.0	....
	7 ft. 6 in.	I2	3.5	....
		I3	2.0	....
	Average		2.8	

① Kip/ft is 1000 lb. per ft. of width of wall; 4 ft. for compressive and 8 ft. for racking specimens.
② Specimens did not fail. Test discontinued.

role in any particular type of construction. Our knowledge of the heat transfer in inclosed air spaces is limited at present, but it may be said, in general, that such transfer will increase with the temperature by significant amounts due primarily to the large variation in radiation. Walls of this nature are subject to much greater variation in construction than solid walls, since more or less mortar is forced into air spaces, depending upon chance and the individual workman."

The symbols used to represent the various coefficients of heat transmission are defined in the American Society for Heating and Ventilating Engineers' Guide as follows:

U—Transmittance or over-all coefficient of heat transmission, air to air, is the amount of heat in Btu transmitted in one hr. per sq. ft. of wall for a difference in temperature of one degree Fahrenheit between the *air* on the inside and outside of the wall.

k—Thermal conductivity is the amount of heat expressed in Btu transmitted in one hr. through one sq. ft. of a homogeneous material one in. thick. for a difference in temperature of one degree Fahrenheit between the two *surfaces* of the material.

C—Thermal conductance is the amount of heat expressed in Btu transmitted in one hr. through one sq. ft. of nonhomogeneous material for the thickness or type under consideration for a difference in temperature of one degree Fahrenheit between the two *surfaces* of the material.

f—Surface conductance is the amount of heat expressed in Btu transmitted by radiation, conduction and convection from a surface to the air surrounding it, or vice versa, in one hr. per sq. ft. of the surface for difference in temperature of one degree Fahrenheit between the *surface* and the surrounding *air*.

f_i—inside surface conductance.

f_o—outside surface conductance.

a—Thermal conductance of an air space is the amount of heat expressed in Btu transmitted by radiation, conduction and convection in one hr. through an area of one sq. ft. for a temperature difference of one degree Fahrenheit.

R—Resistance or resistivity is the reciprocal of transmission, conductance or conductivity; that is, the reciprocal of U is over-all, or *air* to *air*, resistance. The reciprocal of C is internal, or *surface* to *surface*, resistance; the reciprocal of k is internal resistivity per in. thickness; similarly for the reciprocals of f and a.

Extensive tests have been conducted to determine the heat transmission of various types of wall constructions. These tests are reported in Research Paper No. 291, previously referred to; University of Minnesota Engineering Experiment Station Bulletin No. 12, Thermal Conductivity of Building Materials, by Frank B. Rowley and Axel B. Algren; and in the Guide and other publications of the American Society of Heating and Ventilating Engineers.

All of the data reported indicate that it is possible to compute the transmittance, conductance and resistance of walls constructed of combinations of materials with reasonable accuracy if the coefficients of the various components are known; the total resistance of a composite wall being equal to the sum of the resistances of its separate parts including the resistances of air spaces and the surface resistances. The transmittance (U) is obtained by taking the reciprocal of the resistance.

Conductance and resistance coefficients of various elements of walls are listed in Table 6-22. These coefficients are taken from the 1949 edition of the ASHVE Guide except as indicated in the footnotes.

If it is desired to obtain the resistance of, for example, a wall consisting of 4-in. high density brick, 8-in. tile, furring, wood lath and plaster; utilizing these coefficients, the following equation is obtained:

$$\text{Resistance} = 0.17 + 0.44 + 1.67 + 0.91 + 0.40 + 0.61 = 4.20$$

$$\text{The transmittance U} = \frac{1}{4.20} = 0.24$$

In the above equation, the first term is the outside surface resistance; the second term is the resistance of 4 in. of high density brick; the third term is the resistance of 8 in. of hollow tile; the fourth term is the resistance of the air space; the fifth term is the resistance of the lath and plaster; and the sixth term is the inside surface resistance. The total is the thermal resistance (R) of the wall. The reciprocal of the resistance is the thermal transmittance (U) in Btu transmitted in one hr. through one sq. ft. of wall per degree difference in outside and inside temperature.

The resistance of the wall assemblages illustrated in Fig. 6-5 and 6-6 are given in Table 6-23, together with the resistance of various types of finish assemblages, including insulation. These values simplify the calculations of wall coefficients as illustrated by the following example:

Compare the resistance of two 8-in. brick and tile walls, one furred and plastered on ⅜-in. plasterboard or gypsum lath, and the other having 1-in. blanket insulation in addition:

	Uninsulated	Insulated
8-in. brick and tile wall	2.33	2.33
1-in. furring, ⅜-in. plasterboard, plaster	1.33	....
1-in. furring, 1-in. blanket, ⅜-in. plasterboard, plaster	....	4.12
Total Resistance (R)	3.66	6.45
Transmittance $U = \frac{1}{R} =$	0.27	0.16

TABLE 6-22
TABLE OF HEAT TRANSMISSION COEFFICIENTS
from A.S.H.V.E. Guide (1949) and other sources as indicated

MATERIAL	Transmittance (U) or Conductance (C)	Resistance (R) $(R = \frac{1}{U} = \frac{1}{C})$
Inside Surface (Still air)	(f_i) 1.65	($1/f_i$) 0.61
Outside Surface Ordinary (15 mph. wind velocity)	(f_o) 6.00	($1/f_o$) 0.17
4″ Brick (low density)	1.25	0.80
8″ Brick (low density)	0.62	1.60
8″ Brick (average value)①	0.96	1.04
12″ Brick (low density)	0.42	2.40
12″ Brick (average value)①	0.64	1.56
4″ Brick (high density)	2.30	0.44
8″ Brick (high density)	1.15	0.87
12″ Brick (high density)	0.76	1.31
4″ Hollow Tile	1.00	1.00
4″ Hollow Tile (average value)①	0.97	1.03
6″ Hollow Tile } 2 cells in direction of heat flow	0.64	1.57
8″ Hollow Tile } 2 cells in direction of heat flow	0.60	1.67
10″ Hollow Tile } 2 cells in direction of heat flow	0.58	1.72
8″ Hollow Tile (average value)①	0.485	2.06
8″ Hollow Tile (3-cell divided mortar joints)②	0.40	2.50
12″ Hollow Tile (3 cells in direction of heat flow)	0.40	2.50
16″ Hollow Tile (1-10″ and 1-6″, each having 2 cells in direction of heat flow)	0.31	3.23
Stucco (1″ thick)	12.50	0.08
Cement Mortar (½″ thick)	24.00	0.04
Plasterboard (⅜″) and plaster, (total thickness ⅞″)	2.40	0.42
Wood lath and plaster (total thickness, ¾″)	2.50	0.40
Metal lath and plaster (total thickness, ¾″)	4.40	0.23
Plaster, cement (1″ thick)	8.00	0.13
Plaster, gypsum (1″ thick)	3.30	0.30
Frame, 1″ yellow pine or fir sheathing and bldg. paper	0.86	1.16
Frame, 1″ yellow pine lap siding	1.28	0.78
Frame, 1″ fir sheathing, bldg. paper and yellow pine lap siding	0.50	2.00
Insulating blanket, fiber; typical 1″	.27	3.70
2″	.135	7.40
Insulation, Mineral wool, all forms 1″	.27	3.70
2″	.135	7.40
3″	.090	11.10
Insulation, Rigid fiber boards, typical ½″	.66	1.52
$\frac{25}{32}$″	.42	2.38
1″	.33	3.03
Yellow pine or fir boards, typical $\frac{25}{32}$″	1.02	.98
Maple flooring, $\frac{13}{16}$″	1.48	.67
Roofing: Asphalt composition or prepared	6.50	.15
Built-up—⅜″ thick	3.53	.28
Shingles: Asbestos—cement	6.00	.17
Asphalt	6.50	.15
Wood	1.28	.78
Plywood, $\frac{5}{16}$″ typical	2.56	.39
Glass, single	1.13 (U)	.88
double (as storm sash)	.45 (U)	2.20
Doors, wood 1¾″ thick	.51 (U)	1.96
Air Space (more than ¾″) 40° F. mean temp.	(a) 1.10	(1/a) 0.91

① National Bureau of Standards R. P. No. 291.
② University of Minn., Eng. Experiment Station, Bulletin No. 12.

TABLE 6-23

RESISTANCE (R) OF VARIOUS ASSEMBLAGES OF WALL AND INSULATING MATERIALS

Computed from Coefficients Recommended in A.S.H.V.E. Guide, 1949 Edition, and Other Sources as Indicated

(Wind Velocity Outside Assumed at 15 mph)

Construction	R
Bare Walls ①	
a—8″ solid brick, including surface resistances	1.82
b—8″ brick and tile, including surface resistances	2.33
c—8″ structural tile (2 cells); flat bed, including surfaces	2.45
d—8″ structural tile (3 cells); recessed bed ②, including surfaces	3.28
e—9½″ cavity, all brick, including surfaces and inside air space	2.73
f—9½″ cavity, brick and tile, including surfaces and inside air space	3.24
Finishing Assemblages	
Exterior stucco, ¾″ thick	.06
Cement mortar, ½″ thick	.04
Interior plaster, ½″ thick	.15
1″ furring, metal lath, ¾″ plaster	1.14
1″ furring, wood lath, plaster	1.31
1″ furring, ⅜″ plasterboard, ½″ plaster	1.33
1″ furring, ½″ rigid insulating board, ½″ plaster	2.58
1″ furring, 1″ blanket insulation, ⅜″ plasterboard, plaster	4.12
1″ furring, 1″ blanket insulation, ½″ rigid insulating board, ½″ plaster	5.37
2″ furring, 1″ blanket insulation, ⅜″ plasterboard, plaster	5.03
2″ furring, 1″ blanket insulation, ½″ rigid insulating board, ½″ plaster	6.28
2″ furring, 2″ batt fill, ⅜″ plasterboard and plaster	7.82
2″ furring, 2″ batt fill, ½″ rigid insulating board, ½″ plaster	9.07
Insulation applied in cavity of walls (e) and (f)	
2″ Vermiculite concrete (20 lb. per cu. ft.)	2.94
Fiberglass, 1″ thickness	4.61
2″ thickness	7.40
Foamglass, 1″ thickness	3.13
2″ thickness	4.44

① Average conductivity for brick (k=7.5) from National Bureau of Standards R. P. 291.

② University of Minn., Eng. Experiment Station, Bulletin No. 12.

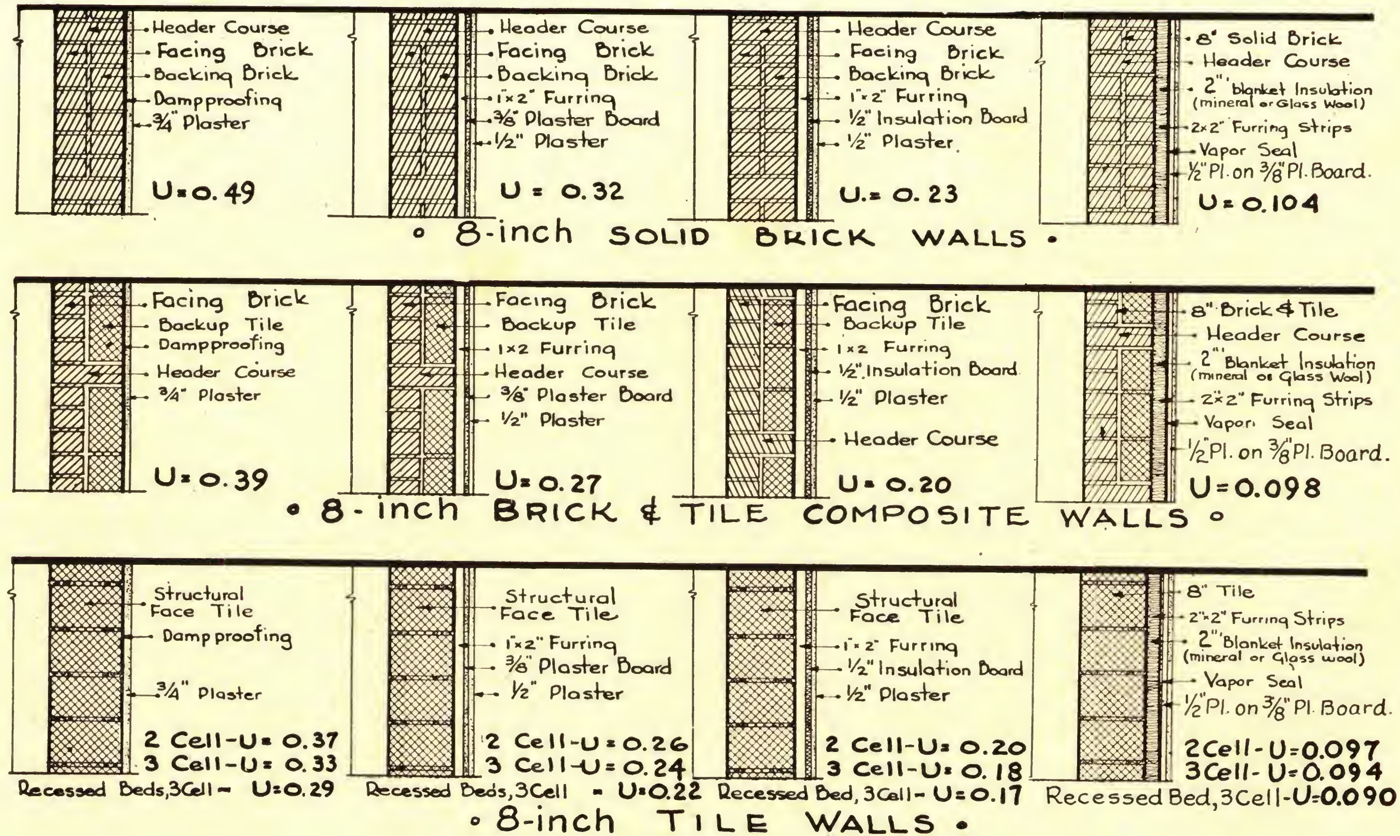


FIG. 6-5

Heat transmission coefficients "U", for nominal 8-in. brick and tile walls in Btu per hour, per sq. ft., per degree Fahrenheit difference in temperature. (Based on a wind velocity of 15 mph.)

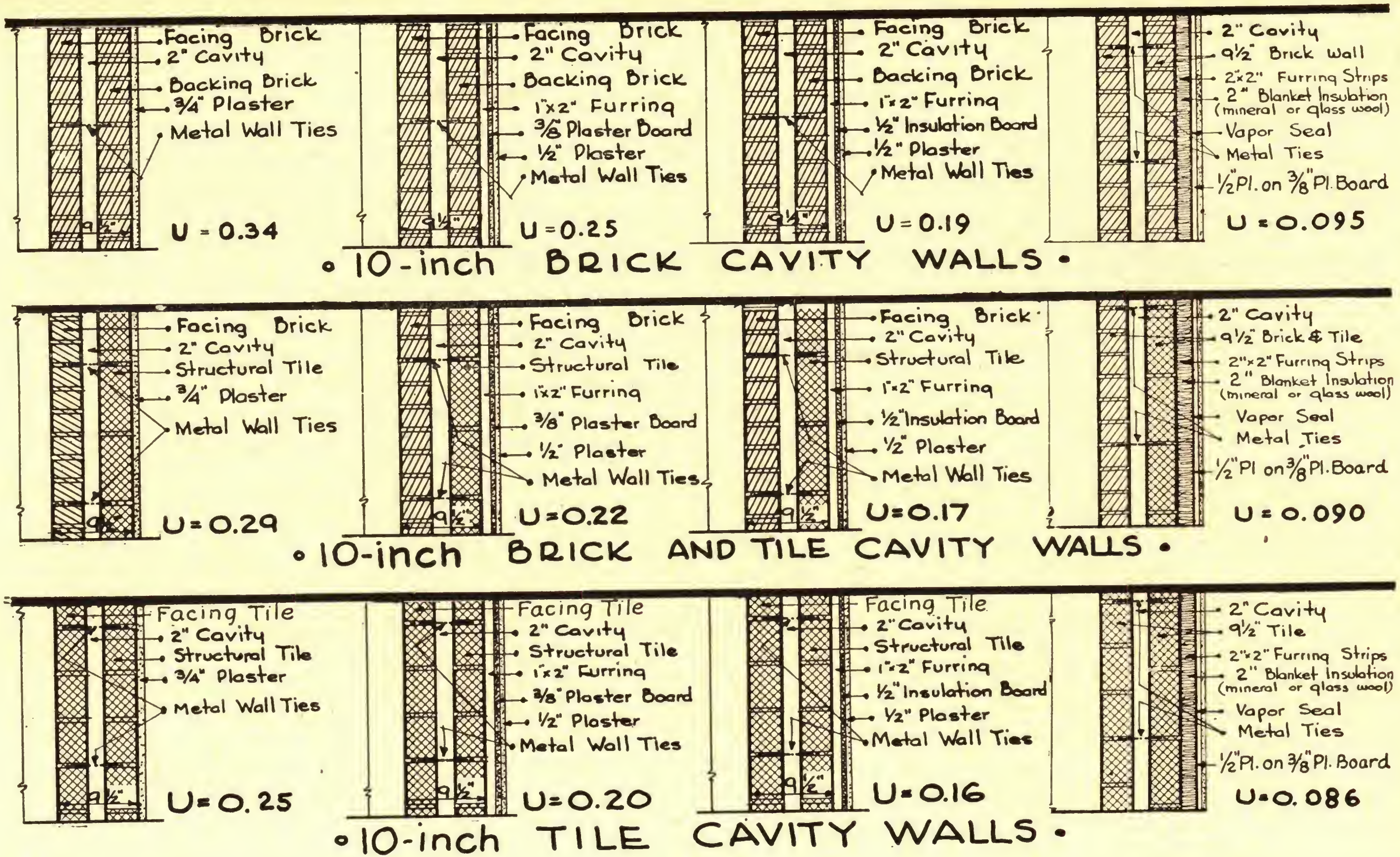


FIG. 6-6

Heat transmission coefficients "U", for nominal 10-in. brick and tile cavity walls in Btu per hour, per sq. ft., per degree Fehrenheit difference in temperature. (Based on a wind velocity of 15 mph.)

607. SOUND RESISTANCE

The sound resistance or sound transmission loss of a wall or floor is expressed as a reduction factor in decibels. A decibel is defined in National Bureau of Standards Report BMS17, "Sound Insulation of Wall and Floor Constructions," by V. L. Chrisler, as follows:

"* * * It has been found that the ear does not respond in proportion to the energy of the sound. As the energy of a sound increases steadily, the response of the ear fails to keep pace with it. There appears to be in the ear a regulating or protective mechanism which, like the well-known mechanism of the eye, protects the organ against excessive stimulation. Experiment shows that the response of the ear is approximately proportional to the logarithm of the sound energy; that is, energies proportional to 10, 100 and 1,000 would produce in the ear effects proportional to 1, 2, and 3, respectively.

"A slight modification of this logarithmic scale has come into general use to measure sound energy and the amount of noise reduction. It is called the decibel scale. This scale merely multiplies the number of the logarithmic scale by 10. The unit of this scale, the decibel, is a rather convenient unit as it is approximately the smallest change in energy that the average ear can detect. For this reason this unit has frequently been called a sensation unit.

"The decibel scale is suitable for measuring ratios of sound intensity. To measure absolute noise levels the zero value is assigned to a definite level, i.e., a level of 20 decibels corresponds to an energy 100 times that corresponding to the zero value."

The sound transmission losses of many walls and floor constructions have been determined in the laboratory by various investigators; however, it has been found that the absolute values of the reduction factors are materially affected by the conditions and methods of test so that, while data obtained by different methods agree as to the relative values of different panels, absolute values are not comparable unless the method and the rooms in which the measurements are made are similar. For this reason, only transmission losses determined by the National Bureau of Standards will be reported in this section.

Tests to determine the sound insulation of various wall and floor constructions were started at the National Bureau of Standards in 1922 and have been carried on continuously since that time.

Many of the results obtained are reported in BMS17 and supplements which were published in 1939, 1940 and 1947. The authors make the following statement regarding factors which control the transmission of sound through walls and floors:

"From work that has been done in the laboratory on homogeneous walls of various types, it has been determined that the weight of the wall per unit area is the most important factor in determining its sound insulation. Of secondary importance are the nature of the material and the manner in which it is fastened at the edges. There is a rather popular misconception that fiberboard and sheet lead have special properties as sound insulators. Actually, if only the sound insulating properties of the materials by themselves are considered, a sheet of steel is a slightly better sound insulator than a sheet of lead or fiberboard of the same weight per sq. ft., because of the greater stiffness of the steel, but the difference is not usually great enough to be of practical value. In small panels the manner of clamping the edges is of

importance, but for a large panel the manner in which the edges are held makes but little difference in its value as a sound insulator.

"However, attention should be called to the fact that the sound insulation factor (transmission loss in decibels) for homogeneous walls is not directly proportional to the weight per unit area, but increases less rapidly than this factor, actually being proportional to the logarithm of the weight per unit area. This means that a high degree of sound insulation cannot be obtained in a homogeneous wall unless the wall is made exceedingly heavy.

"Shortly after the study of sound insulation was undertaken it was found that the insulating value of a wall of given weight could be increased considerably if the wall were broken up into two or more layers. The surface on which the sound strikes is set in vibration as a diaphram, but the energy from this surface has to be transferred to the next layer and then to the other side. By a proper combination of materials this energy transfer may be made quite small, and the smaller this transfer the better the wall is as a sound insulator. When a wall is thus broken up into layers, the problem becomes more complicated and it is more difficult to predict what the sound insulation factor will be."

* * *

"For heavy building construction, such as load-bearing walls, a double wall will increase the sound insulation, but the fillers which have been tried seem to be of little value. However, with a masonry wall satisfactory sound insulation can be obtained in other ways which often give better results than a double wall.

"In most cases it is customary to apply the plaster directly to the masonry. In this case, the wall becomes a solid unit and its weight is the most important factor. If only 3- or 4-in. tile are used there is not sufficient weight to give satisfactory sound insulation in most cases. The problem then is one of attaching the plaster surfaces to the masonry core so as to secure as much sound insulation as possible.

"To obtain some idea of the effect of keeping the plaster surface as independent of the masonry as possible, wood furring strips were tied to a 4-in. tile wall with wires which had been imbedded in the mortar joints. Waterproofed paper was nailed to these furring strips, then metal lath and plaster were applied. The object of using paper was to prevent the plaster from pushing through the metal lath and bonding to the masonry core. It was found that this type of wall was a trifle better than an 8-in. brick wall, although it weighed approximately one-third as much. When this was first tried out, it was believed that the method of attaching the furring strips might make considerable difference in the sound transmission. The measurements which have been taken indicate that this feature is of minor importance. There are several patented methods of attaching furring strips, but it is believed that for this type of wall construction there is little difference in the sound insulation values of these systems as long as the plaster surface is held away from the masonry, not making direct contact at any point.

"When these furred-out masonry panels were in position, conversational tests were made as well as the usual sound-transmission measurements. In every case it was found that the sound of a conversation carried on in an ordinary tone of voice was barely audible to a listener on the other side, provided he was listening intently, but that he was unable to understand anything that was said. Moreover, if there were the slightest noise in the

listener's room, he failed to detect any sound of the conversation on the other side of the panel. It should be borne in mind that the rooms in which these tests were made had bare concrete walls and were so situated that no distracting noises entered from the outside. If these rooms had contained draperies and furniture to absorb part of the sound, and if there had been some noise due to traffic or other causes, the conversation would have been inaudible."

As previously indicated, the sound insulation factor for homogeneous walls is proportional to the logarithm of the weight per unit area. Fig. 6-7, reproduced from Bureau of Standards Research Paper No. 48 by V. L. Chrisler and W. F. Snyder, shows this relationship and may be used to determine the approximate reduction factor of homogeneous walls provided they are tested under conditions similar to those employed at the National Bureau of Standards. The methods of test used at the Bureau of Standards are described in Research Paper RP800; "Recent Sound Transmission Measurements" by V. L. Chrisler and W. F. Snyder. Fig. 6-7 is not applicable, however, to non-homogeneous construction such as structural tile partitions furred, lathed and plastered.

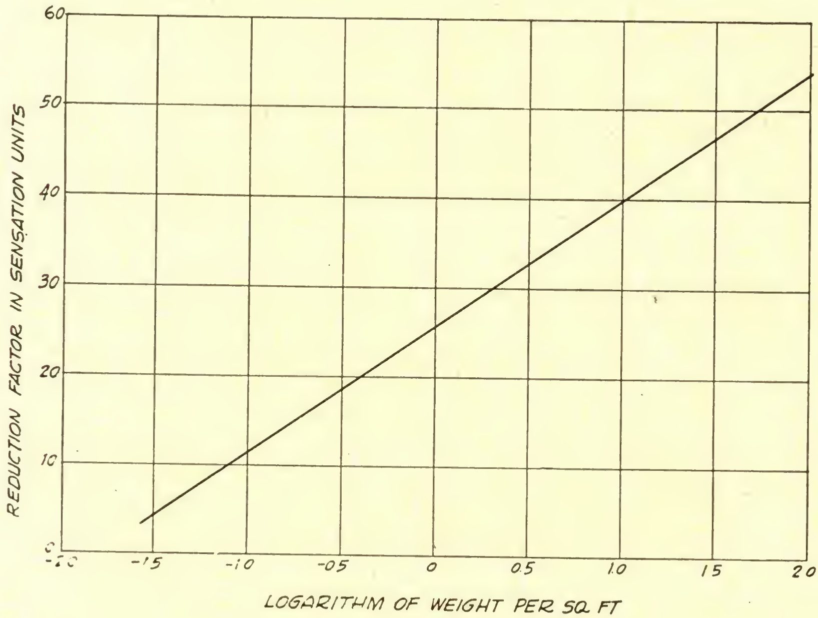


Fig. 6-7

Approximate reduction factor of homogeneous walls

Table 6-24, reproduced from data included in BMS17, shows the transmission loss in decibels for typical conventional type wall and partition constructions. The reduction factors given are the average of determinations made at frequencies ranging from 250 or less to more than 3000 cycles per sec.

TABLE 6-24

SOUND TRANSMISSION LOSS IN DECIBELS

Material in Test Panel	Weight psf.	Average Reduction Factors
12″ Hollow Tile—two different types of units, plaster both sides, brown and white finish	65	48.6
12″ Hollow Tile—two different types of units, plaster both sides, brown and white finish	66	50.0
8″ Hollow Tile—plaster both sides, brown and smooth white finish	48	49.8
6″ Hollow Tile—plaster both sides, brown coat and smooth white finish	39	47.1
6″ Hollow Tile—plaster both sides, brown coat and smooth white finish	37	45.7
4″ Hollow Tile—plaster both sides, brown coat and smooth white finish	29	44.0
4″ Hollow Tile—plaster both sides, brown coat and smooth white finish	29	43.5
3″ Hollow Tile—plaster both sides, brown coat and smooth white finish	28	44.4
8″ Hollow Tile (Heath cubes)—plaster both sides, brown coat and smooth white finish	55	51.0
4″ Hollow Tile—wood furring, paper, metal lath and plaster both sides	34	57.5
4″ Hollow Tile (on pads)—wood furring, paper, metal lath and plaster both sides	34	58.3
8″ Hollow Tile—2 units, 1¾″ apart, filled with Flax-li-num and ½″ Flax-li-num pads at top, bottom and sides of one wythe	50	59.2
8″ Brick—plaster both sides, brown coat and smooth white finish	97	56.7
8″ Brick—plaster both sides, brown coat and smooth white finish	87	57.2
3¾″ Brick—lime plaster with smooth lime finish on both sides—no furring	49.0	50.2
3¾″ Brick—gypsum plaster with smooth lime finish on both sides—no furring	49.0	53.7
2¼″ Brick—plaster both sides on wired furring strips	36.5	53.5
2¼″ Brick—nailed furring strips and plaster both sides	38.2	55.2
2¼″ Brick—nailed furring strips and Insulite as plaster base	33.3	54.6
2¼″ Brick—plaster both sides directly on brick surface	31.6	48.8
Wood and Sheet Rock—studding filled with porous gypsum	12.3	44.8
Wood and Gypsolite—studding filled with porous gypsum	11.8	42.4
Wood and asbestos—wood studs, ½″ asbestos on one side, joints filled	Not given	27.4
Wood and Celotex—wood stands, ½″ Celotex on one side, joints filled	Not given	26.7

608. FIRE RESISTANCE

The fire resistance of walls, partitions and floors, unless otherwise defined, is generally understood to be based on the Standard Method of Fire Tests of

Building Construction and Materials of the American Society for Testing Materials, ASTM Designation E119-.

Specifications for this test provide that the temperature on the exposed (fire side) of the panel shall be controlled by the standard time-temperature curve and that the points which determine the character of this curve are:

1000° F. at 5 min.
1300° F. at 10 min.
1550° F. at 30 min.
1700° F. at 1 hr.
1850° F. at 2 hr.

Immediately following the fire endurance test, the panel is subjected to a hose stream test in which the stream is delivered through a 2½-in. hose, discharging through a standard 1⅛-in. nozzle, at a distance of 20 ft. from the center of the panel. For a two-hour rating, the water pressure at the base of the nozzle is 30 psi and the duration of the application is 2½ min.

The following are the conditions of acceptance for non-bearing walls and partitions:

1. The wall or partition shall have withstood the fire endurance test without passage of flame or gases hot enough to ignite cotton waste for a period equal to that for which classification is desired.

2. The wall or partition shall have withstood the fire and hose stream test without passage of flame, or gases hot enough to ignite cotton waste, or of the hose stream test.

3. Transmission of heat through the wall or partition during the fire endurance test shall not have been such as to raise the temperature on its unexposed surface more than 250° F. (139° C.) above its initial temperature.

For load-bearing construction there are the additional requirements that during the fire endurance and hose stream tests the construction shall be loaded "in a manner calculated to develop theoretically as nearly as practicable the working stresses contemplated by the designer," and the construction must withstand the loading test within 72 hr. after completion of the fire and hose stream tests.

The hose stream test consists of exposing the specimen to the standard fire exposure for a period equal to one-half of that indicated as the resistance period but not for more than 1 hr., immediately after which the specimen is subjected to the impact, erosion, and cooling effects of a hose stream, delivered through a standard fire nozzle at pressures varying from 30 to 45 psi, depending upon the resistance period. Constructions are classified according to their ability to withstand the standard tests, but the tests are not a measure of the suitability of the construcion for use after fire exposure.

Fire resistance ratings of brick and tile walls are summarized in National Bureau of Standards Report, BMS92, "Fire Resistance Classifications of Building Constructions", published in October 1942.

Regarding the test specimens, the authors of BMS92 state:

"Most of the brick test walls were laid up in 1:1:6 portland cement-lime mortar. Some solid walls were laid up in 1:3 portland cement or 1:3 lime mortar, these proportions being based on volume of cementing materials to that of damp sand. They were tested restrained within the panel frame, unrestrained with freedom for expansion and deflection at sides and top, or under a constant working load of 160 psi of gross area, except that the 4-in. walls

without pilasters were loaded to 80 psi. The ratings for 8-in. or heavier solid walls can be taken to apply if laid in any of these mortars. For 4-in. solid walls and all hollow walls the mortar mix should not be leaner than 1:1:6 proportion.

"The structural tile walls were laid in 1:1:4 and those of concrete blocks in 1:1:6 portland cement-lime mortar. The respective ratings given should be taken as applying where mortar mixes not leaner than these are used. The walls were loaded during the fire test to 80 psi of gross area.

"The hollow brick walls with 70 per cent of solid material were loaded to 120 psi and with 87 per cent of solid material to 160 psi of gross area. The brick cavity wall made up of 2 wythes of brick laid flat with a ¼ in. metal tie between them for each 3 sq. ft. of surface is rated for an average working load of 40 psi of gross area which may be applied eccentrically to give a maximum stress at the fire-exposed surface of 80 psi.

"When the test data were directly applicable, the ratings were taken generally at a little below the average of the test results where there was an appreciable variation. A few ratings are based on limited interpolation and extension of a line of related test data made by the method given in Section 1 of Appendix B. (Method of Estimating Fire Resistive Periods).

"The constants for use in the formula for determining the fire resistance of plastered walls given near the end of Section 1 of Appendix B were derived from available test results, and all the ratings for plastered walls were made by the use of this formula. The average thickness of plaster applied in the different series of tests ranged from ½ to ¾ in. The thickness for which ratings are given are those most likely to obtain in building construction considering what must be done to obtain a true surface. Thus ratings for plastered brick and concrete block walls are for ½-in. plaster thickness and in the case of structural clay tile for ⅝-in. thickness. Ratings for other thicknesses can be obtained by substituting the appropriate constants in the formula.

"Tests of four hollow concrete-unit walls show the effect of one coat of plaster on the fire-exposed side to be about the same as for one coat of plaster on the unexposed side. No tests have been made with plaster on the unexposed side only of clay hollow tile walls. However, the ratings given in the table for plaster on one side are believed to have sufficient margin of safety to be applicable for either condition.

"The fire resistance period, when combustible members are framed into the wall, is taken to be reached when an average temperature rise of 325° F., or a maximum rise of 422° F., is attained at a point 3½ to 4 in. from the side not exposed to fire.

"Average test results show that the ratings for unplastered walls into which combustible members project will be the following part of the rating for the same unplastered walls not thus modified. These factors may be applied where definite test data are lacking.

(1) All walls with 1 cell in wall thickness.......two-fifths
(2) 8-in. walls with 3 cells in wall thickness......two-fifths
(3) 8-in. walls with 2 units in wall thickness......two-fifths
(4) 8-in. solid walls..........................two-fifths
(5) All walls with 2 cells in wall thickness.........one-half
(6) All 12-in. walls (except walls with 1 or 2 cells in wall thickness)........................two-thirds

"If such walls are plastered with ½-in. 1:3 sanded gypsum plaster on the side opposite the framing, add ½ hr. if the rating for combustible members framed into the unplastered walls is 2½ hr. or less, and add 1 hr. if the rating is 3 hr. or more. For ⅝-in. plaster thickness these increments are somewhat greater, as indicated in the ratings for walls of clay or shale structural tile. For plaster on the same side as the framing and for plaster on one side of walls with combustible members entering from both sides, no increase in fire resistance due to the plaster can be assumed, since the wall may be exposed to fire on the unplastered side.

"If hollow spaces (cells) surrounding the ends of combustible members are filled solidly with masonry the rating will be the same as for incombustible or no members framed into the wall, except that the rating cannot exceed the rating for solid walls of the same thickness with combustible framing. These limits can be taken as follows:

8-in. walls unplastered.................................2 hr.
8-in. walls plastered on fire-exposed side or both sides..2½ hr.
12-in. walls unplastered...............................7 hr.
12-in. walls plastered on fire-exposed side or both sides..8 hr.

Tables 6-25, 6-26, 6-27, 6-28, 6-29, and 6-30, reproduced from BMS92, give the fire resistance ratings for various types of brick and tile walls and partitions.

TABLE 6-25

LOAD-BEARING BRICK WALLS

ominal wall thickness	Type of wall	Material	Ultimate Fire Resistance Period				
			Incombustible members framed into wall or no framed-in members			Combustible members framed into wall	
in.			No plaster *hr.*	Plaster on one side *hr.*	Plaster on two sides *hr.*	No plaster *hr.*	Plaster on exposed side *hr.*
4..........	Solid.............	Clay or shale..	1¼	1¾	2½	......	......
8..........	Solid.............	Clay or shale..	5	6	7	2	2½
12.........	Solid.............	Clay or shale..	10①	10①	12①	8	9
8..........	Hollow Rolok.....	Clay or shale..	2½	3	4	1	1½
12.........	Hollow Rolok.....	Clay or shale..	5	6	7	3	4
8..........	Hollow Rolok Bak.	Clay or shale..	4	5	......	......	......
12.........	Hollow Rolok Bak.	Clay or shale..	10	10	......	......	......
9 to 10.....	Cavity...........	Clay or shale..	5	6	7	2	2½
4..........	Solid.............	Concrete.....	1½	2	3	......	......
8..........	Solid.............	Concrete.....	6	7	8	2½	3
12.........	Solid.............	Concrete.....	13	14	16	8	9
4..........	Solid.............	Sand-lime....	1¾	2½	3	......	......
8..........	Solid.............	Sand-lime....	7	8	9	2½	3
12.........	Solid.............	Sand-lime....	10②	10②	12②	9	10

① Based on load failure. If based on temperature rise, the fire resistance period would be 12 hr. for the unplastered wall, 13 hr. for plaster on one side, and 15 hr. for plaster on both sides.

② Based on wall failure at 10 hr. If based on temperature rise, the fire resistance period would be 14 hr. for the unplastered wall, 15 hr. for plaster on one side and 17 hr. for plaster on both sides.

NOTE—Not less than ½-in. 1:3 sanded gypsum plaster is required to develop the above ratings for plastered walls.

The ratings for structural clay tile partitions represent the lower averages of the results of fire tests conducted at the National Bureau of Standards and Ohio State University (Engineering Experiment Station Bulletin No. 104, "A Study of the Fire Resistance of Building Materials", January 1940).

Fire resistive ratings listed in Table 6-31 are based upon standard fire tests at Ohio State University, the results of which are included in the publication of the Structural Clay Products Institute, "Fire Resistance of Facing Tile Walls".

TABLE 6-26

LOAD-BEARING WALLS OF CLAY, OR SHALE, CORED BRICK

Nominal wall thickness	Units in wall thickness	Cells in wall thickness	Minimum percentage of solid materials in units	Ultimate Fire Resistance Period				
				Incombustible members framed into wall or no framed-in members			Combustible members framed into wall	
in.				No plaster *hr.*	Plaster on one side *hr.*	Plaster on two sides *hr.*	No plaster *hr.*	Plaster on exposed side *hr.*
8.............	1	1	70	2½	3	4	1	1½
12............	1	2	70	5	6	7	3	4
8.............	2	2	87	5	6	7	2	2½
12............	3	3	87	10①	10①	12①	8	9

① Based on load failure. If based on temperature rise, the fire resistance period would be 11 hr. for the unplastered wall, 12 hr. for plaster on one side, and 14 hr. for plaster on both sides.

NOTE—Not less than ½ in of 1:3 sanded gypsum plaster is required to develop the above ratings for plastered walls.

The method of estimating fire resistive periods of constructions similar to others for which the fire resistive periods are known or of composite constructions for which the fire resistive periods of various components are known is described in Section 1, Appendix B of BMS92. Regarding the derivation of the general formula the authors state:

"In most cases the fire resistance period will be determined by the temperature rise on the unexposed side of the wall, and it is on this criterion that the following method of interpolation and expansion is based.

"According to the general theory of heat transmission, if walls of the same material are exposed to a heat source that maintains a constant temperature of the surface of the exposed side, and the unexposed side is protected against heat loss, the time at which a given temperature will be attained on the unexposed side will vary as the square of the wall thickness. (See 'Heat Transmission' by Wm. H. McAdams (1933) and 'Mathematical Theory of Heat Conduction' by Ingersoll and Zobel (1913).

"In the standard fire test, which involves specified conditions of temperature measurement and a fire that increases the temperature at the exposed surface of the wall as the test proceeds, the time required to attain a given temperature rise on the unexposed side will be different from where the temperature on the exposed side remains constant at the initial exposure temperature for any period. It has been found that comparisons fairly

TABLE 6-27

STRUCTURAL CLAY TILE PARTITIONS

[Laid in portland cement-lime mortar]

Description	Ultimate Fire Resistance Period							
	No plaster		Plaster on unexposed side		Plaster on fire exposed side		Plaster on both sides	
	(A) *hr min*	(B) *hr min*	(A) *hr min*	(B) *hr min*	(A) *hr min*	(B) *hr min*	(A) *hr min*	(B) *hr min*
One cell in wall thickness								
3-in. partition, units not less than 50 per cent solid	0 10	0 20	0 20	0 20	0 30	0 45	0 45	1
4-in. partition, units not less than 40 per cent solid	10	20	20	25	30	45	45	1
4-in. partition, units not less than 50 per cent solid	15	25	25	30	45	1	1	1 15
6-in. partition, units not less than 30 per cent solid	15	20	25	35	45	1	1 15	1 30
6-in. partition, units not less than 40 per cent solid	20	25	30	40	1	1 05	1 15	1 30
Two cells in wall thickness								
4-in. partition, units not less than 50 per cent solid	25	30	35	45	1	1 15	1 15	1 30
4-in. partition, units not less than 60 per cent solid	30	35	40	1	1 15	1 30	1 30	2
6-in. partition, units not less than 45 per cent solid	45	1	1	1 15	1 15	1 30	1 30	2
Double shells plus one cell in wall thickness								
4-in. partition, units not less than 45 per cent solid	20	25	30	35	45	1	1 15	1 30
One cell in wall thickness, cells filled with broken tile, crushed stone, slag, cinders, or sand, mixed with mortar								
4-in. partition, units not less than 40 per cent solid	1 15	1 15	1 30	1 30	1 45	1 45	2 30	2 30
6-in. partition, units not less than 30 per cent solid	2	2	2 30	2 30	2 30	2 30	3 30	3 30

NOTES—Ratings in column (A) are for dense hard-burned clay or shale tile.
Ratings in column (B) are for medium-burned clay tile. All shale tile are classed under (A).
Not less than ⅝-in. thickness of 1:3 sanded gypsum plaster is required to develop the above ratings for plastered partitions.

TABLE 6-28

LOAD-BEARING FURRED AND CAVITY WALLS OF CLAY, OR SHALE, STRUCTURAL TILE

Nominal wall thickness *in.*	Description	Ultimate Fire Resistance Period: Plaster on one side *hr.*	Ultimate Fire Resistance Period: Plaster on two sides *hr.*
8	8-in. 40 per cent solid tile plus 2-in. furring tile	3½	5
10	Two 3¾-in. 40 per cent solid tile with 2-in. air space between	....	4

NOTE.—Not less than ¾-in. portland cement plaster or stucco outside and ⅝-in. gypsum plaster inside is required to develop these ratings.

TABLE 6-29

LOAD-BEARING WALLS OF CLAY, OR SHALE, STRUCTURAL TILE

Nominal wall thickness *in.*	Units in wall thickness	Cells in wall thickness	Minimum percentage of solid materials in units ①	Ultimate Fire Resistance Period — Incombustible members framed into wall or no framed-in members: No plaster *hr.*	Plaster on one side *hr.*	Plaster on two sides *hr.*	Combustible members framed into wall: No plaster *hr.*	Plaster on exposed side *hr.*
8..........	1	2	40	1¼	2	3	¾	1½
8..........	1	2	43	1½	2	3	¾	1½
8..........	1	2	46	1¾	2½	3½	1	1¾
8..........	1	2	49	2	3	4	1¼	2
8..........	1	3 or 4	40	1¾	2½	3½	¾	1½
8..........	1	3 or 4	43	2	3	4	¾	1½
8..........	1	3 or 4	48	2½	3½	4	1	1¾
8..........	1	3 or 4	53	3	4	5	1¼	2
12..........	1	3	40	2½	3½	4	2	3
12..........	1	3	45	3	4	5	2½	3½
12..........	1	3	49	3½	4	6	3	4
12..........	2	3 or 4	40	3½	4	6	2	3
12..........	2	3 or 4	45	4	5	6	2½	3½
12..........	2	3 or 4	53	5	6	7	3	4
16..........	2 or 3	4 or 5	40	5	6	8	4	5
16..........	2 or 3	4 or 5	43	6	7	9	4	5
16..........	2 or 3	4 or 5	46	7	8	10	5	6
16..........	2 or 3	5 or 6	49	8	9	11	5	6
16..........	2 or 3	5 or 6	51	9	10	12	6	7
16..........	2 or 3	5 or 6	53	10	11	13	7	8

① The percentage of solid material in units given above, in the case of walls built up of units of different designs, is to be taken as the weighted average for the units at the courses in the wall where the average prcentage is the lowest.

NOTES—All tile is to conform with ASTM specifications from the standpoint of strength and absorption.

Not less than ⅝-in. of 1:3 sanded gypsum plaster is required to develop the above ratings for plastered walls.

TABLE 6-30

LOAD-BEARING BRICK-FACED WALLS OF CLAY, OR SHALE, STRUCTURAL TILE

Nominal wall thickness *in.*	Description	Ultimate Fire Resistance Period	
		No plaster *hr.*	Plaster inside *hr.*
8	4-in. 40 per cent solid tile plus 4-in. brick face	3½	4
12	8 in. 40 per cent solid tile plus 4-in. brick face	6	7
12	8-in. 70 per cent solid tile plus 4-in. brick face	①10	①

① Based on wall failure under load. If based on temperature rise, the ultimate, fire resistance period would be 11 hr. for the unplastered wall and 12 hr. for the wall plastered on one side.

NOTE.—Not less than ⅝-in. of 1:3 sanded gypsum plaster required to develop the above ratings for plastered walls.

TABLE 6-31

STRUCTURAL FACING TILE PARTITIONS

Nominal Wall Thickness, in.	Description	Ultimate Fire Resistance
6	Glazed or unglazed facing tile cored not in excess of 25 per cent, 2 units in wall thickness.	3 hr.
6	2 inches glazed or unglazed facing tile cored not in excess of 25 per cent and 4 in. structural tile cored not in excess of 40 per cent, plastered on unglazed side with ¾ in. gypsum sand plaster (1:3 by volume).	3 hr.
4	Glazed or unglazed facing tile cored not in excess of 25 per cent, plastered on unglazed side with ¾ in. of gypsum sand plaster (1:3 by volume).	2 hr.
4	Glazed or unglazed facing tile cored not in excess of 30 per cent, plastered on unglazed side with ¾ in. vermiculite plaster.	2 hr.
4	Glazed or unglazed facing tile meeting requirements of ASTM Specifications for Structural Clay Load-Bearing Wall Tile, C34, except that the shells of solid shell horizontal cell units shall be not less than ¾ in. thick, plastered on unglazed side with ¾ in. gypsum sand plaster (1:3 by volume).	1 hr

NOTE.—All plastered partitions plastered on unexposed side.

consistent with test results can be obtained by assuming the variation to be according to some lower power of n than the second. The fire resistance of a wall of a single material and design can be then expressed by the formula:

$$R = (cV)^n \quad \text{.........(1)}$$

Where R = fire resistance period,

c = coefficient depending on the material, design of wall, and the units of measurement of R and V,

V = volume of solid material per unit area of wall surface, and

n = exponent depending on the rate of increase of temperature at the exposed face of the wall.

"For walls of a given material and design it was found that an increase of 50 per cent in volume of solid material per unit area of wall surface resulted in a 100 per cent increase in the fire resistance period. This relation gives a value of 1.7 for n. The lower value for n as compared with 2 for the theoretical condition of constant temperature of the exposed surface is to be expected as the rising temperature at the exposed surface would tend to shorten the fire resistance period of walls qualifying for relatively higher ratings.

"For walls otherwise similar but of different thicknesses the general formula takes the following form:

$$R_2 = R_1 \left(\frac{V_2}{V_1}\right)^{1.7} \ldots\ldots (2)$$

where V_1 and V_2 are the respective volumes of solid materials per unit area of wall surface, and R_2 and R_1 the corresponding fire resistance periods."

It has also been found that the fire resistance period of a composite wall may be expressed by a formula similar to the general formula (1) for walls of a single material and design. This formula may be written:

$$R = (c_c V_c)^n, \ldots\ldots\ldots (3)$$

Where R and n are defined as for Equation (1),

V_c = sum of the unit volumes (V_1, V_2, V_3) of the component laminae defined as for Equation (1)

c_c = a weighted average of the coefficients (c_1, c_2, c_3) of the component laminae defined as for Equation (1) $= \dfrac{(c_1V_1+c_2V_2+c_3V_3)}{V_c}$

The fire resistance period of a composite wall may be expressed in terms of the fire resistance periods of the conjoined wythes or laminae by substituting for c_c in Equation (3) its value in terms of the component parts of the wall as follows:

$$R = (c_1V_1 + c_2V_2 + c_3V_3)^n, \ldots\ldots\ldots (4)$$

If R_1, R_2, R_3, are fire resistance periods of walls of a single material or design (component laminae) having volumes of solid material per unit area of wall surface of V_1, V_2, V_3, and coefficients c_1, c_2, c_3, then substituting in equation (1)

$$R_1 = (c_1V_1)^n,$$
$$R_2 = (c_2V_2)^n,$$
$$R_3 = (c_3V_3)^n,$$

Equation (4) may then be written

$$R = (R_1^{1/n} + R_2^{1/n} + R_3^{1/n})^n.$$

Substituting 1.7 for n and 0.59 for $1/n$, the general formula for composite walls becomes:

$$R = (R_1^{0.59} + R_2^{0.59} + R_3^{0.59})^{1.7} \ldots\ldots\ldots (5)$$

It will be noted that the fire resistance period has been expressed in terms of the fire resistance periods of the component laminae of the wall, which need not be of the same material and design.

The method of estimating the effect of plaster or air spaces on fire resistance is described in BMS92 as follows:

"If the fire resistance period of a wall is known and if it is desired to find the fire resistance period when one coat of ½-in. 1:3 sanded gypsum plaster is added, the solution is as follows:

$$R = (R_1^{0.59} + 0.3)^{1.7} \ldots\ldots\ldots (6)$$

R_1 = fire resistance period of the unplastered wall in hours;

R = fire resistance period of the plastered wall in hours;

0.3 = an average value derived from tests (use 0.6 if plastered on both sides).

"Use 0.37 for one coat of ⅝-in. 1:3 sanded gypsum plaster and 0.75 if plastered on both sides. For ¾-in. thickness of this plaster, use 0.45 for application on one side and 0.90 for plaster on both sides. The value of the constant is directly proportional to the thickness of plaster.

"In like manner, it was found that the effect of continuous air spaces separating wythes or laminae of a wall by distances of ½ to 3½ in. may be estimated by the use of the values 0.3 and 0.6 for one and two spaces, respectively."

As an example of the application of the methods of estimating fire resistance, assume that it is desired to determine the fire resistive period of a wall consisting of 4 in. of brick, 4 in. of structural clay tile and 4 in. of glazed facing tile, with a continuous air space not less than ½ in. wide between the structural tile and the facing tile, and that the following fire resistive periods are known:

4 in. of brick plus 4 in. of structural tile, unplastered..3½ hr.
4 in. of facing tile plastered on unexposed side........2 hr.

First, substitute in equation (6) to determine the fire resistance period of 4 in. of facing tile, unplastered, as follows:

$$2 = (R_1^{0.59} + 0.45)^{1.7}$$

Where R_1 = fire resistance of unplastered partition in hours.

This equation is easily solved by logarithms:

$\text{Log } 2 = 1.7 \log (R_1^{0.59} + 0.45)$
$R_1^{0.59} = 1.0534$
$R_1 = 1.092 = 1$ hr. and 6 min.

1.092 hr., the fire resistance of an unplastered 4-in. glazed partition, may be substituted in equation (5) together with 3½ hr. fire resistance of 4 in. of brick plus 4 in. of facing tile to obtain the fire resistance of the composite construction.

$$R = (1.092^{0.59} + 3.5^{0.59})^{1.7}.$$

Solving this equation by means of logarithms;

$$R = 7.02 \text{ hr.}$$

To determine the effect of the air space, 7.02 hr., the fire resistance of the composite construction, without an air space, is substituted in equation (6).

$$R = (7.02^{0.59} + 0.3)^{1.7}.$$
$$R = 8.243 = 8 \text{ hr. and } 15 \text{ min.}$$

It will be noted from Table 6-30 that the fire resistance of a 12-in. wall consisting of 4 in. of brick and 8 in. of 40 per cent solid tile unplastered is 6 hr. and the fire resistance of a 12-in. wall consisting of 4 in. of brick and 8 in. of 70 per cent solid tile unplastered is 10 hr.

The structural tile of the above example was 40 per cent solid and the glazed facing tile 75 per cent solid; consequently, the fire resistance of the wall described would be expected to fall between the resistances of the two walls listed in Table 6-30.

609. THERMAL EXPANSION

The coefficient of thermal expansion of brick masonry varies, depending upon the coefficients of both the brick and the mortar. An average value may be taken as 0.000004 in. per in. per degree F.

Theoretically the expansion of a solid brick wall 100 ft. long due to a temperature change of 70 to 100° F. might be expected to cause serious cracking if expansion joints were not provided to take up the movement of the wall. However, this theory has not been borne out by actual experience. Many such walls which have been exposed to severe temperature changes over a period of many years show no evidence of cracks which might be attributed to expansion. The reason for this apparent contradiction of the theory has not been determined; it may be due to compensating movements of the masonry units and mortar, to the compressibility of the mortar, or to a combination of several factors.

Since from 90 to 95 per cent of structural tile walls consist of tile units, the coefficient of thermal expansion of structural tile masonry might be expected to be of the same order as the coefficient for the units.

As indicated in Section 414, an average value of the coefficient of thermal expansion of clay or shale tile is 0.0000033 per degree F.; and while the data on fire clay (buff burning) units are scarcely sufficient to justify definite conclusions, a value of 0.0000025 per degree F. is suggested as a probable average value in the absence of more accurate knowledge of the thermal expansion of the particular unit.

610. RESISTANCE TO RAIN PENETRATION

The principal factors affecting the watertightness of masonry walls are indicated in the Building Materials and Structures Report BMS82 of the National Bureau of Standards, "Water Permeability of Walls Built of Masonry Units", by Cyrus C. Fishburn, issued under date of April 15, 1942. This publication contains data obtained from tests on 140 walls representing 39 kinds of units, 14 kinds of workmanship and 10 kinds of mortar. Mr. Fishburn's comprehensive report is a valuable contribution to the literature on the design and construction of masonry walls to resist the penetration of moisture and deserves careful study by all who are interested in the subject. The following is a summary of the data reported in BMS82:

(a) Workmanship. As found in previous investigations (Report BMS7, October 18, 1938), workmanship was the most important single factor affecting the permeability of the walls tested. Most of the walls on which data are reported in BMS7 were constructed with two kinds of workmanship, designated as A and B. Workmanship A was characterized by completely filled joints,

both horizontal and vertical, the bed joints being spread level (not furrowed) and the vertical joints (head and collar) filled solidly with mortar. In workmanship B a minimum amount of mortar was used. The bed joints were deeply furrowed, the head joints were only partially filled, brick being buttered at the outer edge and no mortar was placed in the collar joint. The workmanships used in the construction of the walls reported in BMS82 included both A and B with the addition of intermediate types. Workmanship A′ was similar to workmanship A except the bed joints were lightly furrowed. Workmanship F was similar to workmanship B except that the back of the facing wythe and in the case of 12-in. walls, the back of the center wythe was parged. These workmanships were further varied in the construction of brick and tile walls. Workmanship F′ was similar to workmanship F except the head joints particularly at the header courses were filled solidly with mortar. Workmanship G and G′ were similar to F and F′ except that the parging was applied to the face of the backing rather than to the back of the facing.

(b) Brick Suction. The data included in Report BMS82 indicate that the suction rate of the brick when laid also influences the performance of the walls in the moisture penetration test. Suction rate of brick is defined as the amount of water, in grams, absorbed by a surface of 30 sq. in. placed in water to a depth of ⅛ in. for 1 min.

Data of BMS82 indicate that brick walls of the same thickness constructed with similar mortars and workmanship showed best results in the permeability test when the suction rate of the brick when laid was under 20 grams (.7 oz.) and that walls constructed of brick having suction rates when laid exceeding 60 grams (2.1 oz.) were significantly more permeable, regardless of the type of workmanship or mortar used.

(c) Mortars. The report indicates that the important property of mortar affecting the permeability of brick walls is water retentivity. The flow of the mortar when used is of lesser importance, but nevertheless is a factor. Flow of mortar is related to its water content and, generally speaking, for any given ingredients, the higher the water content, the greater the flow.

Mortar flow is determined on a flow table which is described in ASTM Specifications C91- for Masonry Cement as follows:

"*Flow Table.* The flow table apparatus shall consist of a rigid metal frame and a circular rigid table 10 in. in diameter with a shaft attached perpendicular to the table top. The table with attached shaft shall be mounted on the frame in such a manner that it can be raised and dropped vertically through a fixed height of ½ in. by means of a rotated cam. The table top shall have a plane surface and be of non-corrodible metal. The table and the attached shaft shall weigh 9 plus or minus 0.1 lb. The end of the shaft shall not strike upon the cam at the end of the drop. The surfaces of the table and the frame which come into contact at the end of the drop shall be plane and parallel with the upper surface of the table and the material of these parts shall be hard metal to prevent cushioning effect. The contact faces of the cam and the shaft shall be such that the table does not rotate more than one revolution during the 25 drops. The frame shall be attached rigidly to a concrete pedestal which shall be attached rigidly to the floor. The concrete pedestal shall be at least 8 in. sq. or in diameter at the top and at least 25 in. in height with a base suitable for rigid attachement to the floor and shall weigh at least 100 lb. The table top, after the frame has been

mounted on the pedestal, shall be level along any two diameters at right angles to each other in both the raised and the lowered position.

"*Flow Mold.* The flow mold shall be made of non-corrodible material and shall be 4 in. in inside diameter at the base, 2.75 in. in inside diameter at the top, and 2 in. in height."

In determining the flow, the mold filled with mortar is placed on the flow table and the mold is removed immediately, after which the table is dropped through a height of ½ in. 25 times in 15 sec. The flow is the resulting increase in diameter of the mortar mass expressed as a percentage of the original diameter (4 in.); that is, a mortar flow of 100 per cent indicates that the diameter of the mortar mass after being subjected to 25 drops of the flow table was 8 in.

The measure of water retentivity is the flow of the mortar after suction for 1 min., expressed as a per cent of initial flow. In conducting the water retentivity test, the mortar is brought to an initial flow of from 100 to 115 per cent and is then subjected to a vacuum of 2 in. of mercury for 60 sec., after which the flow is again determined. If the initial flow of the mortar were 110 per cent and the absolute flow after suction were found to be 77 per cent, the flow after suction used as a measure of water retentivity would be 70 per cent; that is, 70 per cent of the initial flow.

As previously indicated, 10 kinds of mortar were used in the construction of the walls reported in BMS82. However, most of the walls were constructed of 2 mortars of the same composition; one part cement, one part lime putty or hydrate and six parts sand by volume. The mortar containing lime putty had a water retentivity of 80 per cent while the water retentivity of the mortar containing hydrate was only 45 per cent.

The data indicate that except for very low brick suctions, 10 grams (.35 oz.) or under, the permeabilities of walls constructed with the mortar of low water retentivity were significantly greater than similar walls constructed with the mortar of high water retentivity. The author also includes in the report comments from construction records, from which it may be noted that the mortar of low water retentivity was difficult to apply as a parging to brick of low suction and that when used with such brick, there was excessive bleeding of the mortar joints. The report states "The brick masons preferred to use mortar 2 (high water retentivity) rather than mortar 5 (low water retentivity) and their complaints about the brick being either too dry or too wet were usually made when using mortar 5. The walls that were rated as 'good' or 'excellent' and that were also easily constructed were built with mortars having a high water retentivity, using low absorptive brick or medium absorptive brick that had been pre-wetted."

(d) Wall Ratings. Based on their performance in the permeability tests, the walls are rated as: Excellent (E), Good (G), Fair (F), Poor (P) and Very Poor (VP). The author states, however, "In general there was little practical difference between the performance of the walls rated as either 'good' or 'excellent' and it is possible that building walls similar to those rated as 'fair' in the permeability tests would be considered to have a satisfactory resistance to rain penetration, except when subjected to rain and to winds of high velocity for long periods."

(e) All-Brick Walls. Regarding the performance of all-brick walls, the author makes the following comment in the summary:

"There was little practical difference in the performance of walls in which the vertical joints were filled (a) by heavily buttering the brick with mortar before placing them in the walls, (b) by slushing mortar into the joints from above, (c) by pouring in a grout, or (d) by shoving the bricks into a heap of mortar placed on the bed (pick-and-dip method).

"Twelve-in. brick walls in which the head joints were lightly buttered at the exposed faces only, but which contained a mortar parging applied to the backs of both the first and second wythes, were highly resistant to water penetration. Eight-in. walls of this type were more permeable than similar 8-in. walls in which the vertical joints (head and collar joints) were completely filled."

The data substantiate the above statements; both 8 and 12-in. walls constructed with brick having suctions when laid ranging from 0 to 60 grams per min. and with mortar of high retentivity (85 per cent) but built with B workmanship consistently rated "very poor." On the other hand, all types of workmanship in which the head joints or collar joints, or both, were filled solidly with mortar gave satisfactory performances, except when constructed of brick having suction rates exceeding 60 grams (2.1 oz.) when laid or when mortar of low water retentivity (45 per cent) was used. It would seem therefore that the important consideration insofar as workmanship is concerned is the complete filling of vertical joints and that any methods which accomplish this may be expected to give satisfactory results with proper materials.

(f) Grouted Walls. Grouted walls listed as workmanship H rated as "good" with one exception, which rated "fair" and in which a grout of unusually high cement content was used, which is not recommended for this type of construction. From the data it would appear that grouted masonry may be expected to produce walls highly resistant to rain penetration, even accompanied by high winds, and that the performance of grouted masonry walls in resisting moisture penetration may be considered comparable to walls constructed with the other types of workmanship investigated. In building a grouted wall, the construction technique is relatively simple and depends perhaps less on the human element than any of the other types of workmanship. For this reason, it might be expected that results obtainable in the field with grouted masonry would more nearly approach laboratory results than those obtainable with other types of workmanship, except under most careful supervision.

(g) Cored Brick. In the investigation of the effects of cored brick on wall permeability, two walls were built and tested of cored brick and two of solid brick, from each of two plants. The cored and the solid brick from each plant were alike, except for the coring. Regarding the performance of these walls, the author states "The data for the individual walls show that all had a high resistance to water penetration. Walls containing cored brick were slightly less permeable than those containing the solid brick, but the difference in permeability was of little practical importance." As a possible explanation for the decreased permeability of the cored brick walls, the author makes the following observation; "Although the mason placed about the same amount of mortar in the bed joints of all the walls, the cored brick tended to settle in the mortar bed and the walls containing the cored brick were of less height than those containing the solid brick by one-half a course in 18 courses."

(h) Cavity Walls. The theory of cavity wall construction is that moisture may penetrate the outer wythe, flow to the bottom of the cavity and escape to

the outside through weep holes provided for that purpose. Flashings are provided over openings to prevent moisture from reaching the inner wythe at these points. The tests of cavity walls verified what appeared to be an almost obvious assumption, that if the two wythes of the wall are spaced two in. apart and connected only by metal ties, none of the moisture which penetrates the outer wythe will be transmitted to the inner surface of the inner wythe.

Tests of cavity walls filled with Palco Wool as an insulating material indicate that unless extreme care is taken to make the outer wythe highly resistant to moisture penetration, the moisture that penetrates the outer portion of the wall may be transmitted by the insulating material to the inner wythe. For this reason filled insulation in cavity walls should be used with caution unless adequate provision is made to prevent transmission of moisture through the insulating material.

(i) Brick and Hollow Tile Walls. Data on "Permeability of Walls with Brick Facing and Backings of Hollow Units" indicate that high resistance to moisture penetration can be obtained with this type of construction when the wall contains a parge coat (either on the back of the facing or on the face of the backing) and, in addition, the head joints between brick headers are filled solidly with mortar. With one exception, all walls constructed of workmanship F, in which the head joints were not filled solidly, rated from fair to very poor, while with two exceptions, all walls of workmanship F′, in which the head joints between header brick were solidly filled, rated from fair to excellent.

(j) All-Tile Walls. Data on two walls (one side-construction and one end-construction), constructed of 8 x 12 x 12-in. scored four-side load-bearing tile are reported. This type of unit would not ordinarily be used in the construction of exposed walls, and the rating on these walls of "very poor" cannot be considered typical of hollow tile construction. However, regarding the construction of these walls, the author states, "The shells in the head joints of the side-bearing tile were difficult to butter and much less mortar was used in them than for the solid head joints in the wall constructed of end-bearing tile." All data on the permeability of masonry walls seems to indicate that faulty head joints are the principal contributing factor to leakage and since, as indicated above, it is very difficult to produce a satisfactory head joint 12 in. high on a ¾-in. shell, it would seem that for the construction of exposed hollow tile walls that will be subjected to severe exposures (heavy rains, accompanied by high winds) double shell and cored shell tile, or single shell units having over-all shell thickness exceeding the minimum shell thickness requirements of ASTM Specifications C34— for Structural Load-Bearing Tile, should be recommended for head joints exceeding 5 in. and for all sizes where superior performance is desired.

611. PLASTER AND STUCCO ADHESION

Tests at the National Bureau of Standards to determine the adhesion of plaster to various backings were reported by J. P. C. Peter in the September 1925 issue of the American Architect. The Prefatory Abstract of this report states:

"This paper describes the nature of the various backings commonly employed with wall plasters, and physical tests on the adhesion of gypsum plaster

TABLE 6-32

ADHESION OF GYPSUM PLASTER TO VARIOUS BACKINGS

Kind of backing	Per cent Absorption by the Backing	Adhesion, psi (Mean of Two or More Specimens)	Factor of Safety ①
Lath:			
1. Wooden Lath, No. 1	....	2.1	50
2. Metallic Laths			
(a) Sheet metal	....	1.6	38
(b) Expanded metal	....	4.3	103
(c) Woven wire	....	2.4	58
3. Plaster Board			
(a) Gypsum			
(1) Single-ply board ...	....	6.0	144
(2) Three-ply board	....	....	....
(b) Fibre	....	2.3	55
4. Wooden lath on bituminous composition	....	4.8	115
5. Sheet metal strips on bituminous composition	....	2.3	55
Masonry:			
1. Brick:			
(a) Sand-lime brick	13.4	19.0	455
(b) Cement	....	21.5	515
(c) Red shale	5.6	12.7	305
(d) Common red clay	18.8	13.5	324
Common red clay	15.5	15.1	362
2. Concrete (1:2:4 by volume)......	....	15.6	374
3. Tile			
(a) Gypsum	....	7.2	173
(b) Clay Tile			
(1) Surface			
(a) Soft②	24.2	16.2	388
(b) Medium	14.5	16.0	384
(c) Hard	11.1	19.5	468
(2) Shale			
(a) Soft	9.5	18.1	435
(b) Medium	7.6	16.9	405
(c) Hard	1.0	28.0	670
(3) Fire Clay			
(a) Soft	13.7	21.9	525
(b) Medium	8.6	14.4	346
(c) Hard	6.9	15.2	364
Hard③	7.4	19.2	460

① Factor of Safety equals adhesion divided by weight of plaster, assumed at 6 psf.
② Square scoring.
③ Combed scoring.
All the other clay tile have dovetailed scoring.
NOTE.—Only those results were considered in which the plaster pulled free of the backings.

to these backings to determine their effectiveness. The gypsum plaster was applied to specimens of the various backings and after the plaster was allowed to age for seven days it was pulled free of the backings and the force required to rupture the bond was determined and recorded.

"The kinds of backings used can be divided into two general types: (1) Masonry and (2) Laths. Under masonry backings are included: (a) Brick,

(b) Tile, and (c) Concrete. Laths may be divided into: (a) Wooden lath, (b) Metallic lath, (c) Plaster board, and (d) Wooden or metallic laths on a bituminous composition backing. These different backings were plastered with the recommended sanded mixes of gypsum plaster about ¾ in. thick. The plaster was retarded so as to set in about 4 hr.

"The size of the specimens of the various backings was about 12 x 14 in., and the area of the plaster was about 9 x 9 in. Embedded in the plaster was a mechanical device through which a force could be applied to pull the plaster from the backings. At the completion of the aging period, the specimens were put in a testing machine and a continually increasing force was applied to the device until the bond between the plaster and backings ruptured.

"The results show that the adhesion of gypsum plaster to masonry backings is very much greater than in the case of laths. The results also show a great difference in the adhesion of plaster to different types of laths."

Table 6-32 is reproduced from Mr. Peter's report and shows the adhesion in psi of the plaster to the various backings. The weight of plaster, assumed in determining the factor of safety, was 6 psf for a ¾-in. plaster thickness.

Tests were also conducted at the National Bureau of Standards to determine the adhesion of plaster and stucco to structural clay tile having various surface finishes. Results of these tests are reported by J. A. Murray and H. D. Foster. Regarding the results, the authors state:

"From these tests tile with combed, grooved, wire cut, or smooth surfaces appear to be acceptable as a base for the application of plaster or stucco. If the tile have been salt glazed or otherwise burned so that a glazed surface is produced, they should not be used as a backing for plaster or stucco."

CHAPTER 7

DESIGN OF BRICK AND TILE WALLS

701. GENERAL

It goes without saying that the design of walls should be predicated upon the use of the structure of which they are a part and the various forces and exposures to which they may be subjected. Where these factors are known with reasonable certainty, the design can be determined by analyzing the stresses induced by the assumed loads and forces and by the selection of materials and types of construction for which, as a result of laboratory tests or performance records, such properties as strength, durability, fire resistance, sound reduction and heat transmission are known. However, in many instances it is either impossible or impracticable (due to cost) to predict the forces and exposures which a proposed structure may encounter. In such instances the designer is faced with the alternatives of either more or less arbitrarily assuming factors to be used as the basis for an engineering or "rational" design or he may base his design on minimum requirements, included in most building codes, for wall thicknesses and unsupported heights and lengths which have been developed from performance records over a long period of time and represent satisfactory performance under average conditions of exposure and loading.

Most will agree that a design based upon definite requirements is preferable to utilizing the "rule of thumb" methods developed through common practice, and frequently an "engineered" design will result in substantial economies over conventional construction. However, it should be emphasized that design based on rational analysis is no better than the assumptions as to exposure, loading, type of construction obtained and, particularly in the case of members to resist bending, the method of support and the degree of fixity or continuity at supports.

Conventional requirements for masonry construction are the result of experience over many years and, while they may not always represent the most economical construction, they are, for the average condition, safe. Consequently, if the engineered design departs substantially from the conventional, the designer is cautioned to take such steps as may be necessary to insure that the quality and details of construction specified are obtained on the job.

702. COMPRESSIVE STRENGTH

The principal loads and forces which produce compressive stresses in walls and buildings are the dead loads, which consist of the weight of the structural elements, and the live loads, which consist of the stored materials, equipment and occupants of the structure, as well as any other applied loads. The magnitude of both dead and live loads may be predicted with reasonable certainty.

(a) Loads. Tables 7-1, 7-2, and 7-3 give the weights of assemblies of conventional building materials used in wall and floor construction for the purpose of determining dead loads. These weights are averages for certain materials which are naturally subject to variation due to change in unit density, and therefore should not be used for shipping or basing weights. They are recommended, however, for general use in design.

TABLE 7-1

WEIGHTS OF BUILDING MATERIALS (VOLUME)

Description of Material	Weight pcf
Brick masonry	120
Structural clay tile masonry walls (average)	60
Structural clay tile partitions (average)	50
Concrete	
Stone or gravel	150
Slag	130
Cinder	115
Haydite	100
Light weight	70–100
Concrete masonry units	
Stone aggregate	90
Lightweight aggregate (average)	58
Stone masonry	160
Mortar	116
Plaster	96
Cement, portland, loose	94
Sand (dry)	100
Lime (hydrated)	40
Cinders	45
Steel	490
Wood (dry):	
Fir	32
Yellow pine	42
Oak	48
Insulation:	
Rock wool (loose)	10
Wood fiber (rigid)	15
Corkboard	9
Granulated cork	6

NOTE: There is more or less variation in the weights of materials. Weights given in Tables 7-1, 7-2 and 7-3 are approximate averages, and may be used for the purpose of determining dead loads.

Live loads associated with various occupancies or uses are included in most building codes. These loads include a sufficient allowance to cover the effects of ordinary impact; however, for special occupancies involving unusual impacts, such as those resulting from moving machinery, elevators, crane-ways, etc., a suitable increase in the assumed live load should be made.

Most building codes contain the requirement that maximum floor loads, for which the building is designed, shall be posted "in a conspicuous place in

TABLE 7-2

WEIGHTS OF BUILDING MATERIALS (AREAS)

Description of Material	Weight psf
Studs, plates and bridging:	
2x4 @ 12 in. to 16 in.	2
2x6 @ 12 in. to 16 in.	3
Joists:	
2x8 @ 20 in.	2
2x8 @ 14 in. and 2x10 @ 18 in.	3
2x10 @ 12 in. and 2x12 @ 16 in.	4
2x12 @ 12 in.	5
Sheathing	3
Hardwood Finish	4
Floor finish of terrazzo, tile, mastic, linoleum, per in. thickness including base	12
Roofing:	
Wood shingles	3
Asbestos shingles	4
Asphalt shingles	6
Slate, ¼ in.	10
Tar and gravel	6
Ready roofing	1
Copper or tin	1
Corrugated iron	2
Clay tile	10–18
Skylights, metal and wire glass	8
Plaster (Gypsum):	
On masonry, ⅝ in.	5
On wood lath	8
On metal lath	10
On suspended metal ceiling	10
Solid, 2 in. with metal studs and metal lath	22
Wood studs, 2x4, wood lath or plaster board, ⅝ in. plaster, two sides	18
Stucco (cement), 1 in. thick	10
Cinder fill, 2 in. thick	7
Cement floor finish, 1 in. thick	12
Asphalt, 2 in. thick	25

each space to which they relate" and that these loads shall not be exceeded.

The following Section 803, Live Loads, which is reproduced from the 1949 edition of the National Building Code recommended by the National Board of Fire Underwriters, is typical of live load requirements of modern building codes and will be found to conform very closely to similar requirements of all nationally recognized codes.

"1. General. (a). Every building and structure shall be designed and erected of sufficient strength in all its parts to sustain safely all live loads depending thereon, whether permanent or temporary, in addition to the dead loads.

"(b) Every temporary support placed in or under a building or structure shall be of sufficient strength to carry safely the load to be supported thereby.

TABLE 7-3

WEIGHTS OF MASONRY WALLS AND PARTITIONS

Description	Pounds per Square Foot Nominal Thickness					
	2 in.	3 in.	4 in.	6 in.	8 in.	12 in.
Brick masonry			37		78	120
Structural clay tile walls①						
5 in. unit height			24	34	42	66②
8 in. unit height			22	32	38	55
12 in. unit height			21	30	34	49
Brick and tile combination wall					63	83
Structural facing tile (Glazed or unglazed)						
5 in. unit height	16½		30	41	50	
8 in. unit height	16		27			
Glazed brick						
2¼ in. unit height	17		37			
Clay tile partitions	15	16	17	24	32	46
Concrete masonry units (8 in. unit height)						
Stone and gravel aggregate			34	50	58	90
Lightweight aggregate (average)			22	31	36	58
Gypsum partitions	10③	13③	13	19		

① Scored for plaster application.
② Two units in wall thickness.
③ Solid.
NOTE: No plaster or stucco finishes included in the above weights.

"2. Floor loads. No floor hereafter erected in a building shall be designed for less than the following live loads per square foot of area uniformly distributed, according as the floor may be intended to be used for the purposes indicated:

Occupancy	Live Load Psf.
Public Buildings:	
Armories	150
Assembly halls, auditoriums, churches, lecture halls and lodge rooms:	
Fixed seats	60
Movable seats	100
Dance halls, exhibition buildings, grandstands, gymnasiums, museums, passenger stations, recreation piers, restaurants	100
City halls, court houses, club rooms	80
School and college classrooms	40
Corridors	100
Theatres:	
Aisles, projection rooms	100

Orchestra floor	60
Balconies	60
Stage floor	150
Institutional Buildings:	
Hospitals, asylums, infirmaries, sanitariums:	
Operating rooms	60
Private rooms	40
Wards	40
Public spaces	80
Laboratories, X-Ray rooms	100
Penal institutions, reformatories, jails and houses of correction:	
Cell blocks	40
Corridors and stairways	100
Nurseries, orphanages, homes for the aged	40
Residence Buildings:	
Public rooms and corridors	100
Other areas	40
Business Buildings:	
Office buildings	80
Factories, work shops—light work	125
Bakeries, laundries	150
Stores, light merchandise	125
Stores, heavy merchandise	250
Storage Buildings:	
Garages	100
Storage warehouses, light	125
Storage warehouses, heavy	250

"When occupancies or uses not listed above are involved, the live load shall be determined in a manner satisfactory to the building official.

"3. Provision for partitions. In office buildings or other buildings where partitions might be subject to erection or rearrangement, provision for partition weight shall be made, whether or not partitions are shown on the plans, unless the design live load exceeds 80 psf.

"4. Concentrated floor loads. Every floor hereafter erected in a business building or storage building shall be designed to sustain safely a concentrated load of 2,000 lb. placed upon any space 2½ ft. sq. wherever such load upon an otherwise unloaded floor would produce stresses greater than the uniformly distributed load for which the floor is designed. Floors in garages and floors used for automotive trucking shall be designed for the maximum wheel loads.

"5. Stairway and balcony railings. Stairway and balcony railings, both exterior and interior, shall be designed to resist a horizontal thrust of 50 lb. per lin. ft. applied at the top of the railing.

"6. Roof loads, including snow loads. (a) Ordinary roofs, either flat or pitched, shall be designed for a load of not less than 20 psf. of horizontal projection in addition to the dead load, and in addition to either the wind or other loads.

"(b) When a roof, in addition to serving as a closure of a building or structure, is to be used as a floor, it shall be designed to carry safely the live load to be imposed but not less than the minimum live load prescribed in this section for floors.

"(c) Accessible ceilings, scuttles, and ribs of skylights shall be designed to support a concentrated load of 200 lb. occupying an area 2½ ft. sq. and so placed as to produce maximum stresses in affected members.

"7. Sidewalk loads. For sidewalks over vaults and areas, the live load shall be 250 psf. uniformly distributed.

"8. Yard and court loads. For yards and courts inside the lot lines the live load shall be taken at not less than 125 psf. uniformly distributed.

"9. Reduction in live loads. (a) No reduction shall be applied to the roof live load.

(b) For live loads of 100 lb. or less per sq. ft., the design live load on any member supporting a floor area of 150 sq. ft. or more may be reduced at the rate of 0.08 per cent per sq. ft. of the total floor area supported by the member, except that no reduction shall be made for areas to be occupied as places of assembly. The reduction shall exceed neither R as determined by the following formula, nor 60 per cent:

$$R = 100 \times \frac{D + L}{4.33L}$$

in which: R = reduction in per cent
D = dead load per square foot of area supported by the member
L = design live load per square foot of area supported by the member.

"For live loads exceeding 100 psf., no reduction shall be made, except that the design live loads on columns may be reduced 20 per cent.

"10. Posting of live loads. The live load for which each floor, or part of a floor, of a business building or a storage building hereafter erected is designed and approved shall be conspicuously posted in that part of the story to which it applies.

"11. Loading restricted. No person shall place, or cause or permit to be placed, on any floor of a building or on any part of a structure a greater load than the approved or accepted safe load."

(b) Working Stresses. The American Standard Building Code Requirements for Masonry, A41.1-1944, prescribes the allowable compressive stresses in masonry for various types of brick and tile walls. Mortar types A, B, and C, referred to in this standard, are similar to the corresponding types defined in Recommended Specifications for Masonry Mortar, Chapter 5.

Type D mortar is a low strength, high lime mortar, proportioned by volume; 0 to ½ part portland cement, 1 to 1¼ parts lime putty, and not more than 3 parts sand for each part of cementitious material or, if accepted under the property specification, the compressive strength of 2-in. cubes at 28 days shall not be less than 75 psi.

The following provisions are quoted from the American Standard Building Code Requirements for Masonry, A41.1-1944:

"Solid Masonry Units. The allowable compressive stresses in pounds per square inch of gross cross-sectional area in solid masonry of solid units shall not exceed the following limits:

BRICK AND OTHER SOLID UNITS OF CLAY OR SHALE; SAND LIME OR CONCRETE BRICK

Average Compressive Strength of units tested in the position taken in the masonry psi	Mortar Type			
	A psi	B psi	C psi	D psi
8,000 plus	400	300	200	100
4,500 to 8,000	250	200	150	100
2,500 to 4,500	175	140	110	75
1,500 to 2,500	125	100	75	50

"Composite Walls. In walls or other structural members, composed of different kinds or grades of units or mortar, the maximum stress shall not exceed the allowable stress for the weakest of the combinations of units and mortar of which the member is composed.

"Hollow Masonry Units. The allowable compressive stresses in pounds per square inch of gross cross-sectional area in masonry of hollow units of structural clay tile or of hollow concrete masonry units shall not exceed the following limits:

Unit	Mortar A psi	Type B psi
Hollow units	85	70

"Cavity Walls and Hollow Walls of Solid Units. In cavity walls and in hollow walls of solid masonry units, the compressive stresses in pounds per square inch of gross cross-sectional area shall not exceed the following:

Solid masonry units with mortar A........................ 125 psi
Solid masonry units with mortar B........................ 100 psi
Hollow masonry units with mortar A...................... 60 psi
Hollow masonry units with mortar B...................... 50 psi
Plain concrete .... 300 psi

Based on the ultimate strength of brick and tile walls, as reported in Chapter 6, these working stresses represent factors of safety varying from approximately 4 to 12.

In most structures the compressive stress in walls is low, rarely exceeding 50 to 60 psi, and consequently is not the critical factor which determines the wall thickness. However, in piers supporting beams or girders and in narrow wall sections, high compressive stresses may be developed and, in such cases, it would appear safe to increase the allowable stresses in compression if the quality of materials and the workmanship are carefully controlled.

(c) Design Formulae. For walls concentrically loaded, the compressive stress is obtained by the well known formula:

$$f = \frac{P}{A} \qquad \text{(1)}$$

Where f = compressive stress in pounds per square inch,
P = total applied loads in pounds,
A = area of wall or pier in square inches.

If the load is applied eccentrically, bending stresses are induced in the wall and the combined stress may be obtained by the formula:

$$f = \frac{P}{A} \pm \frac{Pev.}{I}$$

Where f, P and A are defined as in equation (1),
e = eccentricity in inches,
I = moment of inertia of the wall section, $in.^4$
v = distance from neutral axes of section to point at which stress is determined in inches.

To determine the stresses in the faces of a wall of rectangular cross-section, this formula becomes:

$$f = \frac{P}{A}\left(1 \pm \frac{6e}{t}\right), \quad \ldots\ldots (2)$$

Where t = thickness of the wall.

In the above equation, the sign is plus for the face of the wall on the same side of the neutral axis as the eccentricity and minus for the opposite side.

If an eccentric load applied to a rectangular pier is not on one of the principal axes, as indicated in Fig. 7-1, the total unit stress at any point is obtained from the formula:

$$f = \frac{P}{A} \pm \frac{Pxx_1}{I_y} \pm \frac{Pyy_1}{I_x} \quad \ldots\ldots (3)$$

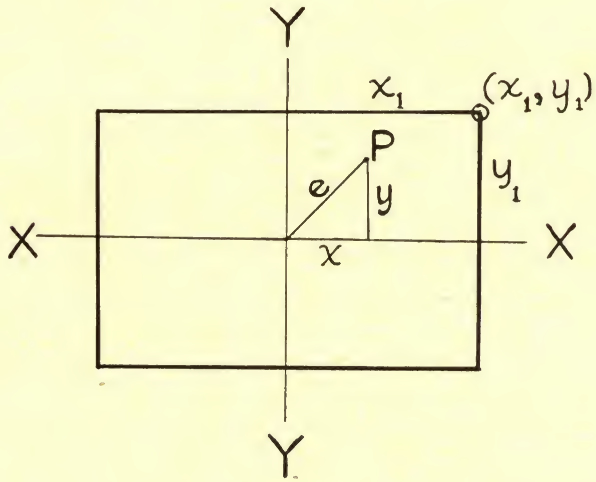


FIG. 7-1

Eccentric load applied to a rectangular pier

Where x, x_1, y and y_1 are as indicated in Fig. 7-1 and I_x and I_y are moments of inertia of the section about the x and y axes, respectively.

The formulae, (1), (2) and (3) are based on the assumption that the section, at which the load is applied, remains plane and that the modulus of elasticity of the wall or pier is constant.

For masonry, stressed not above the allowable working stresses, these conditions are closely approximated and errors resulting from the application of the formulae are insignificant.

(d) Concentrated Loads. When concentrated loads from beams, girders or similar members are carried by brick or tile masonry, provision for spreading the load must be made if working stresses are exceeded. This may be done by means of steel plates or, in the case of hollow walls or walls of structural clay tile, by building 4 in. of solid masonry into the wall as a bearing for concentrated loads.

The American Standard Building Code Requirements for Masonry, A41.1—1944, contains the following provisions regarding beam supports:

"Beams, joists, girders, or other concentrated loads, supported by a wall or pier, shall have bearing at least 3 in. in length upon solid masonry not less than 4 in. thick, or on a metal bearing plate of adequate design and dimensions to distribute safely the loads on the wall or pier."

Compressive stresses resulting from concentrated loads may safely be assumed to spread through a supporting pyramid of masonry whose sides slope not less than 30 degrees to the direction of the load. In determining the resultant stresses in wall sections below concentrated loads, the width of the section may be taken as the base of this pyramid.

703. TRANSVERSE STRENGTH

The transverse loads, which masonry walls are designed to resist, consist of earth pressure or, in the case of saturated earth, hydrostatic pressure, wind pressure, forces due to earthquakes, and in some instances, bomb blasts.

The magnitude of these forces cannot be determined with the same degree of accuracy as the forces producing compressive stresses and, for this reason, the designer is frequently forced to rely upon the performance of existing structures as a basis or at least a guide for a new design.

Designs to resist wind, earthquake and bomb blast forces are based upon equivalent static forces, which it is assumed will produce the same effects on the structure as the moving or kinetic forces. Data are available from which static forces, equivalent to the forces exerted by winds of varying velocities may be predicted with reasonable accuracy, and most building codes prescribe wind loads which all structures must be designed to resist.

When kinetic forces of high frequency, such as earthquakes or bomb blasts, act upon a structure, the resultant stresses are affected, not only by the magnitude and frequency of the kinetic forces, but also by the period of vibration of the structural member. For this reason, the design of structures subjected to high energy forces is much more complicated than when only static forces are involved. The various features involved in such a design are discussed at considerable length by Harold E. Wessman and William A. Rose in their book, "Aerial Bombardment Protection," published in 1942, in which they state the following conclusions:

"a. There is a dearth of accumulated knowledge of quantitative nature on which to base design procedures for energy loads.

"b. There is not enough basic data on the energy distribution at moment of impact and explosion to warrant refined design procedures.

"c. The energy effects may be so localized as to indicate the use of penetration formulas only in getting required thicknesses of structural materials.

"d. Energy formulas for simple units are of value as guides for the use of engineering judgment.

"e. More reports are needed from technical experts in England on the effect of direct hits on different materials of varying thicknesses and with varying conditions of support. More bombing tests such as those recently conducted at Edgewood Arsenal by the U. S. Corps of Engineers are also needed.

"f. The massive structural sections obtained by such design procedures based on energy loads as are available indicate that it is economically impossible to provide full security against bombing."

While many building codes contain the provision that masonry shall be assumed to take no tensile stress, this requirement is inconsistent with minimum wall thicknesses prescribed and the provision, also usually included in building codes, that masonry walls shall be designed to keep the combined stresses, due to dead, live and other loads for which the building is designed, within the limits prescribed.

When the stresses due to wind equivalent to a static load of 20 or 30 psf are analyzed in a non-bearing wall of minimum thickness, it will be found that, as a rule, tensile stresses are developed in the wall. That such walls are safe and can resist forces exerted by winds of 70 to 80 mph velocity is attested by the performances of hundreds of structures throughout the United States, from which it appears that either the static loads, assumed to be equivalent to the wind forces, are too high or that the tensile strength of the masonry is sufficient to resist the tensile stresses. Laboratory test data, reported in Chapter 6, indicate the latter to be the fact.

(a) Wind Loads. Table 7-4, reproduced from American Standard Minimum Design Loads in Buildings and Other Structures, A58.1—1945, gives design wind loads for buildings of various heights.

TABLE 7-4

DESIGN WIND PRESSURES FOR VARIOUS HEIGHT ZONES OF BUILDINGS OR OTHER STRUCTURES

Height Zone (ft.)	Wind Pressure (psf)	Height Zone (ft.)	Wind Pressure (psf)
Less than 50	20	600 to 799	35
50 to 99	24	800 to 999	36
100 to 199	28	1000 to 1199	37
200 to 299	30	1200 to 1399	38
300 to 399	32	1400 to 1599	39
400 to 499	33	1600 and over	40
500 to 599	34		

(b) Working Stresses. Table 7-5, reproduced from the 1949 edition of the Uniform Code of the Pacific Coast Building Officials Conference, gives working stresses in tension and shear for unreinforced masonry.

TABLE 7-5

WORKING STRESSES IN UNREINFORCED MASONRY

Material	Working Stress psi Gross Area					
	Type A Mortar		Type AB Mortar		Type B Mortar	
Grade of Unit	Tension in Flexure	Shear	Tension in Flexure	Shear	Tension in Flexure	Shear
Plain Solid Brick Masonry	20	20	15	15	15	15
Grouted Brick Masonry	25	25	20	20	..	..
Concrete Units—Solid	12	12	12	12	12	12
Hollow Unit Masonry	12①	12①	10①	10①	10①	10①
Cavity Wall Masonry	12①	12①	10①	10①	10①	10①

① Net Area.

Mortar types A and B, referred to in this table, are similar to the corresponding types defined in Recommended Specifications for Masonry Mortar, Section 504.

Mortar type AB is proportioned by volume; 1 part portland cement, ½ part lime, and not to exceed 4½ parts sand, or, if accepted under the property specification, the compressive strength of 2-in. cubes at 28 days shall be not less than 1800 psi.

The Uniform Code also provides: "For combined stresses due to wind and other loads, the allowable unit stresses and the allowable loads on connections may be increased 33⅓ per cent in excess of the values specified. For members carrying wind stresses only, the allowable unit stresses may be increased 33⅓ per cent. In no case shall the section be less than required if the wind stress be neglected."

Reference to the values of modulus of rupture of brick and tile walls, reported in Chapter 6, indicate that allowable working stresses of the Uniform Code provide an ample factor of safety and might safely be increased for brick and side construction tile if the workmanship is controlled.

(c) Design Formulae.

Earth pressures are usually expressed as equivalent fluid pressures which may be obtained by the formula:

$$P = \frac{wh}{2}$$

Where P = total pressure in pounds per square foot,
w = weight of equivalent fluid in pounds per cubic foot
h = height of the wall subjected to pressure, in feet.

Since the hydrostatic pressure on a wall varies from zero at the top to a maximum at the bottom, P, the total pressure, may be assumed as acting at one-third of the height from the bottom of the wall—the centroid of the triangular load diagram.

The tensile stress due to bending may be determined from the formula:

$$f = \frac{Mc}{I}$$

Where f = bending stress in pounds per square inch,
M = bending moment in inch pounds.
c = distance of the extreme fiber from the neutral axes of section in inches
I = moment of inertia of section, $in.^4$

704. MINIMUM WALL THICKNESSES, HEIGHTS AND LENGTHS

The requirements included in the American Standard Building Code Requirements for Masonry, A41.1—1944, for minimum wall thicknesses and unsupported heights and lengths are typical of the provisions included in all building codes and are similar to the requirements of most codes that have been written or revised since 1944, the date of the adoption of the American Standard.

They are based upon the results of tests summarized in Chapter 6, as well as observations of existing structures, and will give satisfactory performance under average conditions of exposure and loading.

As indicated in Section 701, it may not be feasible in many cases to develop an engineering design, particularly for small structures in the residential and commercial classes and, in such cases, minimum requirements may be utilized.

The following provisions are quoted from the American Standard Building Code Requirements for Masonry, A41.1—1944. The mortar types are as described in Section 702.

SOLID MASONRY WALLS

1. Thickness of Solid Masonry Bearing Walls.—(a) The thickness of solid masonry bearing walls shall be sufficient at all points to keep the combined stresses due to live, dead, and other loads for which the building is designed within the limits prescribed by Section 3, Allowable Stresses in Masonry.

(b) Except as otherwise provided in this section, the minimum nominal thickness of solid masonry bearing walls shall be 12 in. for the uppermost 35 ft. of their height, and shall be increased 4 in. for each successive 35 ft. or fraction thereof, measured downward from the top of the wall.

(c) Where solid masonry bearing walls are stiffened at distances not greater than 12 ft. apart by cross walls, or by internal or external offsets or returns at least 2 ft. deep, or by reinforced concrete floors, they may be of 12-in. nominal thickness for the uppermost 70 ft., measured downward from the top of the wall, and shall be increased 4 in. in thickness for each successive 70 ft. or fraction thereof.

(d) In buildings not more than three stories in height, solid masonry bearing walls of the top story may be of 8-in. nominal thickness when the total height of the wall does not exceed 35 ft., provided that such 8-in. walls do not exceed 12 ft. in height and that the roof beams are horizontal.

(e) In residential buildings not more than three stories in height, solid masonry bearing walls may be of 8-in. nominal thickness when not over 35 ft. in height. Such walls in one-story dwellings, and one-story private garages, may be of 6-in. nominal thickness when not over 9 ft. in height, provided that when gable construction is used an additional 6 ft. is permitted to the peak of the gable.

(f) Solid masonry walls above roof level, 12 ft. or less in height, enclosing stairways, elevator shafts, penthouses, or bulkheads may be of 8-in. nominal thickness and may be considered as neither increasing the height nor requiring any increase in the thickness of the wall below, provided the requirements for allowable stresses are met.

2. Thickness of Solid Masonry Nonbearing Walls.—Nonbearing walls of solid masonry may be 4 in. less in thickness than required for bearing walls, but the nominal thickness shall be not less than 8 in. except where 6-in. walls are specifically permitted.

3. Bond.—The facing and backing of solid masonry walls shall be bonded either with at least one full header course in each seven courses, or with at least one full-length header in each 1.5 sq. ft. of wall surface. The distance between adjacent full-length headers shall not exceed 20 in. either vertically

or horizontally. In solid brick walls of more than 8-in. nominal thickness, the inner joints of header courses shall be covered with another header course which shall break joints with the course below.

WALLS OF STRUCTURAL CLAY TILE OR HOLLOW CONCRETE MASONRY UNITS

1. Thickness and Height.—(a) The thickness of walls of structural clay tile or hollow concrete masonry units shall be sufficient at all points to keep the combined stresses due to live, dead, and other loads for which the building is designed within the limits prescribed by Section 3, Allowable Stresses in Masonry.

(b) The minimum thickness of walls of structural clay tile or hollow concrete masonry units shall be not less than that required for solid masonry walls.

(c) Walls of structural clay tile or hollow concrete masonry units shall not exceed 50 ft. in height above the support of such walls.

2. Bond.—(a) Hollow masonry units shall have full mortar coverage of the face shells in both the horizontal and vertical joints.

(b) Where two or more hollow units are used to make up the thickness of a wall, the stretcher courses shall be bonded at vertical intervals not exceeding 34 in. by lapping at least 3¾ in. over the unit below, or by lapping with units at least 50 per cent greater in thickness than the units below at vertical intervals not exceeding 17 in.

(c) Where walls of hollow masonry units are decreased in thickness, a course of solid masonry shall be interposed between the wall below and the thinner wall above.

CAVITY WALLS AND HOLLOW WALLS OF SOLID UNITS

2. Height.—Except as otherwise limited by Section 9-3 (a), cavity walls and hollow walls of solid masonry units shall not exceed 35 ft. in height.

3. Thickness. (a) Cavity walls and hollow walls of solid masonry units shall be not less in thickness than required for solid masonry walls in Section 5, Solid Masonry Walls, provided that 10-in. cavity walls shall not exceed 25 ft. in height.

(b) In cavity walls neither the facing nor backing shall be less than 3¾ in. in nominal thickness, and the cavity shall be not less than 2 in. nor more than 3 in. in width.

4. Bond. (a) In hollow walls of solid masonry units, the facing and backing shall be securely tied together with headers or bonding units, as required for solid masonry walls so that the parts of the wall will exert common action under the load.

(b) Where such walls are decreased in thickness, a course of solid masonry shall be interposed between the wall below and the thinner wall above.

(c) In cavity walls the facing and backing shall be securely tied together with suitable bonding ties of adequate strength. A steel rod 3/16 in. in diameter or a metal tie of equivalent stiffness coated with a noncorroding metal or other approved protective coating shall be used for each 3 sq. ft. of wall surface. Where hollow masonry units are laid with the cells vertical,

rectangular ties shall be used; in other walls the ends of ties shall be bent to 90-degree angles to provide hooks not less than 2 in. long. Ties shall be embedded in horizontal joints of the facing and backing. Additional bonding ties shall be provided at all openings, spaced not more than 3 ft. apart around the perimeter and within 12 in. of the opening.

5. Drainage.—In cavity walls the cavity shall be kept clear of mortar droppings during construction. Approved flashing shall be installed and adequate drainage provided to keep dampness away from the backing.

PARTITIONS

1. Bearing Partitions.—Bearing partitions shall be of sufficient thickness to support their vertical loads without exceeding the stresses specified in Section 3, Allowable Stresses in Masonry, but not less in thickness than required for walls by Section 4, Lateral Support.

2. Nonbearing Partitions.—Nonbearing partitions of masonry shall be built solidly against floor and ceiling construction below and above, and shall not exceed the following unsupported heights:

Thickness exclusive of plaster In.	Maximum unsupported height Ft.
2	9[1]
3	12
4	15
6	20
8	25

[1] Not over 6 ft. in length.

Extensive revisions of sections covering faced walls and veneered walls of the American Standard Building Code Requirements for Masonry, A41.1—1944, are currently (1950) being considered by ASA Committee A41. The following sections, Faced Walls, Walls Veneered with Masonry, and Thin Exterior Masonry Veneer, are recommended good practice for these types of construction. Sections on faced walls and walls veneered with masonry are adapted from the proposed Harrisburg, Pennsylvania, Building Code, compiled by Emil Szendy, and the section on thin exterior masonry veneer is adapted from the San Francisco, California, and proposed Harrisburg Building Codes.

FACED WALLS

1. Material. Materials used in the backing and facing of faced walls shall conform in all respects to the requirements prescribed for such materials. The facing shall be not less than 2 in. thick, net actual thickness, and in no case less in thickness than 1/10 the height of the unit.

2. Thickness. Faced walls shall be not less in thickness than is required for masonry walls of the weakest of the combinations of units and mortars of which the wall is composed. Where bonded to the backing as provided in this section, the facing may be considered a part of the wall thickness.

3. Bond. (a) Brick and structural clay tile facing shall be bonded to the backing as prescribed for solid masonry walls and walls of hollow masonry units, respectively. The vertical joint between the facing and the backing shall be filled with mortar by parging the back of the facing or the face of the backing, whichever is laid first. Ashlar facing of either natural or cast stone shall have at least 10 per cent of the superficial area extending not less than 3¾ in., net actual dimension, into the backing to form bond stones, which shall be uniformly distributed throughout the wall.

(b) Every projecting stone, and, except when alternate courses are full bond courses, every stone not a bond stone shall be securely anchored to the backing with substantial corrosion resistant metal anchors with a cross section of not less than 0.2 sq. in. There shall be at least one anchor to each stone and not less than two anchors for each stone more than 2 ft. in length and 3 sq. ft. in superficial area. Facing stones, 12 sq. ft. in area or more, shall have at least one anchor to each 4 sq. ft. of superficial area.

4. Stresses. The maximum allowable working stresses in faced walls shall not exceed the allowable values for the weakest of the combination of units and mortars of which the wall is composed. Where bonded to the backing as prescribed in this section, the full cross section of both the facing and the backing may be considered in computing the stresses.

WALLS VENEERED WITH MASONRY

1. Scope. The provisions of this section shall govern the installation of exterior masonry veneers exceeding 1½ in. net actual thickness.

2. Material. Material used for veneering regulated by this section shall be of the following net actual thicknesses:

Material	Thickness (In.)
Solid Masonry Units (natural stone, burned clay, cast stone)	Not less than 1⅝
Hollow Masonry Units (burned clay or concrete)	Not less than 3

3. Height. Veneer shall not exceed 35 ft. in height above foundations or other approved support.

4. Attachment of Veneering. (a) The veneering shall be tied into the masonry backing either by a header or by a substantial corrosion resistant metal wall tie for every 300 sq. in. of wall surface, spaced not farther apart than 24 in. vertically or horizontally. Headers shall project at least 3 in. into the backing. At openings in veneer, special care shall be taken to fill all joints flush.

(b) Masonry veneer on frame structures shall be securely attached to the structure with a corrosion resistant metal tie for every 2 sq. ft. of wall surface, spaced not more than 24 in. vertically or horizontally.

5. Stresses. The maximum allowable working unit stresses in the backing of veneered walls shall not exceed the allowable values for masonry of the type which forms such backing. In no case shall the veneering be considered a part of the wall in computing the strength of bearing walls, nor shall it be considered a part of the required thickness of bearing walls.

THIN EXTERIOR MASONRY VENEER

1. Scope. The provisions of this section shall govern the installation of thin exterior masonry veneers 1½ in. or less in thickness.

2. Loads. Thin exterior masonry veneers shall support no vertical load other than the dead load of the veneer above. Veneer above openings shall be supported upon lintels of incombustible material.

3. Support. The weight of masonry veneer shall be supported upon footings or other incombustible structural supports, spaced not over 12 ft. vertically above a point 20 ft. above the adjacent ground elevation. Exterior masonry veneer shall not be attached to wood at any point more than 20 ft. above the adjacent ground elevation and the weight of masonry veneer attached to wood frame walls shall be supported entirely upon footings.

4. Anchorage. Masonry veneer shall be attached to the supporting wall with corrosion resistant metal ties capable of resisting horizontal forces equal to the full weight of the attached veneer and not less than No. 6 W.&M. gauge wire. Ties shall be seated in drilled or cut holes in the veneer and shall be securely fastened to the backing or supports in an approved manner. Metal ties shall be placed in horizontal bed joints and spaced not more than 16 in. on center. The minimum number of anchors provided shall be in accordance with the following schedule:

Area of Veneer Unit	Minimum Number of Anchors
Up to 2 sq. ft.	2
From 2 sq. ft. to 4 sq. ft.	3
From 4 sq. ft. to 12 sq. ft.	4
From 12 sq. ft. to 20 sq. ft.	6
Over 20 sq. ft.	One anchor for each 3 sq. ft. of area

5. Adhesion Type Ceramic Veneer. (a) Material. Units of flat tile or terra cotta which are manufactured with scored backs may be cemented to a masonry or concrete wall or to exterior plaster with portland cement mortar, provided the mortar bond is sufficient to withstand a shearing stress of 50 psi after curing for 28 days. Units shall be not more than 1⅛ in. in thickness and shall not exceed 30 in. in any one dimension, nor 540 sq. in. in superficial area.

(b) Setting. Pieces shall have been soaked in a vat or box of clean water for 1 hr. or more just prior to installation and shall be noticeably damp at the time of setting. At the beginning of setting each day, all walls to be faced shall be drenched with clean water and shall be drenched again with water not sooner than 1 hr. before setting of ceramic veneer.

Just prior to application of mortar coats, a limited area of the wall and the entire back of the piece of ceramic veneer about to be set shall be given a brush coat of neat portland cement and water; brush coats shall be thick and pasty. Immediately thereafter, spread one-half of the mortar coat on a limited area of the wall and the other half on the entire back of the piece of ceramic veneer and tap it in place on the wall so as to completely fill all voids and leave no air pockets. The total thickness of the mortar coat shall average ¾ in. but sufficient mortar should be used to create a slight excess which will be forced out at the joints and the edge of the piece when it is tapped into place.

NOTE: The above procedure is intended for use on masonry walls (brick, hollow tile, concrete) having proper adhesion qualities, and on expanded metal lath walls on which ¼ in. to ½ in. thick scratch coat has been applied; metal lath to be wired to steel studs on 6-in. centers.

705. LATERAL SUPPORT

Lateral support of masonry walls may be provided by cross walls, pilasters or buttresses when the limiting distance is measured horizontally, or by floors or roof when the limiting distance is measured vertically. In either case, there must be adequate anchorage between the wall and the supporting member, and the supporting member must have sufficient strength and stiffness to transmit the horizontal forces to other members or to the ground.

When lateral support is provided by pilasters or buttresses, they must be designed to resist both overturning and sliding, and, when walls, floors or roofs are relied upon for lateral support in addition to the required strength, they must have sufficient stiffness to transmit the horizontal forces without causing excessive deformation of the walls.

Intersecting walls of solid masonry without openings are ideal for transmitting horizontal forces from outside walls to the foundations. When, however, the walls consist largely of windows or other openings between columns or piers, they are of little use in that connection. Special provisions must be made in such cases. Diagonal bracing is most effective and may be readily provided in brickwork unless it interferes with the openings.

The following requirements relating to lateral support and anchoring of walls are quoted from the American Standard Building Code Requirements for Masonry, A41.1—1944:

"Solid masonry walls shall be supported at right angles to the wall face at intervals not exceeding 20 times the nominal wall thickness if laid in Type A, B, or C mortar, and not exceeding 12 times the nominal wall thickness if laid in Type D mortar.

"Walls of structural clay tile or hollow concrete masonry units, and hollow walls of masonry shall be supported at right angles to the wall face at intervals not exceeding 18 times the nominal wall thickness.

"Cavity walls shall be supported at right angles to the wall face at intervals not exceeding 14 times the nominal wall thickness.

"Lateral support may be obtained by cross walls, piers, or buttresses when the limiting distance is measured horizontally, or by floors and roofs when the limiting distance is measured vertically. Sufficient bonding or anchorage shall be provided between the walls and the supports to resist the assumed wind force, acting either inward or outward. Piers or buttresses relied upon for lateral support shall have sufficient strength and stability to transfer the wind force, acting in either direction, to the ground. When the walls are dependent upon floors or roofs for their lateral support, provision shall be made in the building to transfer the lateral forces to the ground.

"Except for window-paneled backs and permissible chases and recesses, walls shall not vary in thickness between their lateral supports. When a change in thickness, due to minimum thickness requirements, occurs between floor levels, the greater thickness shall be carried up to the higher floor level."

(These requirements for lateral support mean, in brief, that if vertical supports, such as columns, piers or cross walls, are provided not more than

the specified number of times the wall thickness apart, there need be no limit on the distance between floors, or when floors are spaced not over the specified number of times the wall thickness apart, piers or other vertical members which afford lateral support are not required.)

"Masonry walls shall be securely anchored to each tier of wood joists or wood beams bearing on them at maximum intervals of 6 ft. in one- and two-family dwellings, and 4 ft. in other buildings, by metal anchors having a minimum cross-section of ¼ x ¼ in., and at least 16 in. long, securely fastened to the joists or beams and provided with split and upset ends or other approved means for building into masonry. Girders shall be similarly anchored at their bearings. Anchors shall be attached in a manner to be self-releasing.

"Masonry walls parallel to wood joists or wood beams shall be provided with similar anchors at maximum intervals of 8 ft. in one- and two-family dwellings, and 6 ft. in other buildings, engaging three joists or beams. Upset and T-ends on anchors shall develop the full strength of the anchor strap.

"Cast-in-place concrete slabs bearing on masonry walls shall be considered as sufficient anchorage for the supporting walls."

706. EXPANSION JOINTS

Many brick and tile load-bearing walls, ranging in length from 100 to 300 ft., have been built without expansion joints and have been exposed to severe temperature changes over a period of many years without any evidence of cracks which might be attributed to expansion.

The current practice of many designers is to build brick and tile masonry walls without expansion joints in heated buildings. However, in unheated buildings where the variations in temperature may exceed 100 degrees F., expansion joints may be required. Also, expansion joints may be required due to the irregularity of the floor plan of the structure. Consequently, it is impossible to state any general rule regarding the installation of expansion joints that will apply to all buildings.

The following is quoted from the 1940 Report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete, and, in the main, applies equally to unit masonry construction:

"*Purpose and Location.* (a) If a reinforced concrete structure is free to expand and contract with variations in temperature or moisture conditions (uniform over the section), no stresses of any importance will be developed. When the movement of the structure is restrained, however, or when temperature or moisture variations are not uniform over the section, stresses are introduced which should be provided for in the design.

"(b) Points requiring special consideration are located where large changes in cross section occur or at corners in long members where expansions or contractions may result in rupture of the side members. No amount of reinforcement will prevent the formation of cracks in a restrained structure in which the required change in length exceeds the extensibility of the concrete, but reinforcement properly designed will serve to distribute the cracks.

"(c) Joints providing a complete separation in the structure, when properly located, can relieve the restraint and prevent or greatly minimize the development of cracks. Such joints should be carefully designed with respect to the type of structure and should provide for the full expected movements without introducing local stresses severe enough to rupture the concrete. They should be located at predetermined points and fully detailed

on the drawings. They may or may not be designed to carry load or distribute stress across the joint. Frequently this type of joint requires some form of protection to keep out extraneous material.

"*Expansion Joints in Long Buildings.* (a) Expansion joints are expensive and in some cases difficult to maintain. They are, therefore, to be avoided if possible. In relatively short buildings, expansion and contraction can be provided for by additional reinforcement. No arbitrary spacing for joints in long buildings can be generally applicable. In heated buildings joints can be spaced farther apart than in unheated buildings. Also, where the outside walls are of brick or of stone ashlar backed with brick, or where otherwise insulated, the joints can be farther apart than with exterior walls of lower insulating value.

"(b) In localities with large temperature ranges, the spacing of joints for the most severe conditions of exposure (uninsulated walls and unheated buildings) should not exceed 200 ft. Under favorable conditions buildings 400 to 500 ft. long have been built without joints even in localities with large temperature ranges.

"(c) In localities with small temperature ranges, the spacing of joints for unheated buildings or with uninsulated walls should not exceed 300 ft. In such localities buildings up to 700 ft. long have been successfully built without joints where other conditions were favorable.

"(d) In roof construction, provision for expansion is an important factor. The joints in the roof may be required at more frequent intervals than in the other portions of the building because of more severe exposure. In some cases expansion joints spaced 100 ft. apart have been provided in roofs and not in walls or floors.

"(e) Joints should be located at junctions in L-, T-, or U-shaped buildings and at points where the building is weakened by large openings in the floor construction, such as at light wells, stairs, or elevators. Joints should provide for a complete separation from the top of the footings to the roof, preferably by separate columns and girders.

"*Retaining Walls.* For retaining walls and similar structures subject to large temperature and moisture changes, vertical construction joints with 'V' notches at the face should be provided at sections, preferably not over 30 ft. apart, with reinforcement carried through the joint. Expansion joints with grooved lock joints should be provided not more than 100 ft. apart for reinforced concrete walls; reinforcement should not be carried through expansion joints. In plain concrete walls similar expansion joints should be provided, preferably not more than 30 ft. apart.

"Construction and expansion joints in the coping and balustrade of retaining walls should be placed over all joints in the wall. Additional joints in balustrade and copings may be desirable."

707. PIERS AND PILASTERS

Piers are free-standing elements of a structure. They differ from pilasters or buttresses in that they are isolated while pilasters and buttresses are bonded to and are integral parts of walls. Buttresses differ from pilasters in that they are usually built with varying cross-section, decreasing in area from the base to the top, while pilasters have a uniform cross-section throughout their height.

Piers, pilasters and buttresses are constructed to support concentrated vertical loads and, in addition to that function, pilasters and buttresses are used to provide additional stiffness and lateral support to walls.

The unsupported heights of piers supporting beams and girders should not exceed 10 times their least dimension when constructed of solid clay masonry units (25 per cent maximum voids) or when the cellular spaces of hollow structural clay tile units are filled with concrete or cement mortar. When constructed with solid masonry units, allowable compressive stress requirements are similar to those for brick masonry. If hollow units are solidly filled with concrete or cement mortar, the allowable compressive stress may be increased 25 per cent over that permitted for masonry of hollow units. Unfilled hollow piers may be used if their unsupported height is not more than four times their least dimension.

The above requirements will ordinarily determine the pier size and cross-sectional area. As an additional check on the required area, the total dead and live load to be supported should not exceed the allowable compressive stress in masonry, times the area. It will generally be found that the actual area is far greater than the required area.

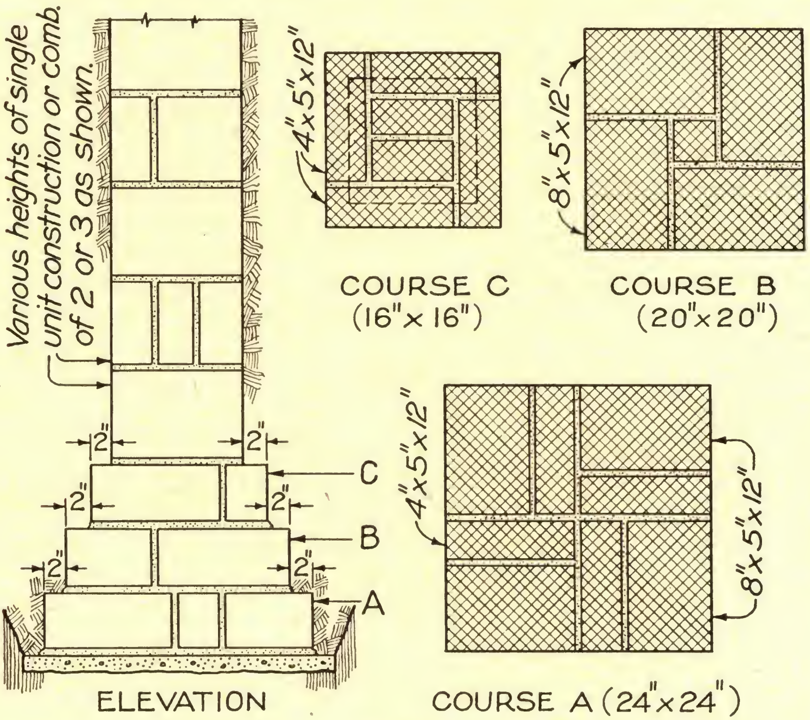


FIG. 7-2

Typical 12-in. structural clay tile pier and footing. Vertical or horizontal cell, hollow or solid masonry unit (25 per cent maximum voids) construction.

It is essential that the point of application of the loads on a pier be near the center of the pier. If the resultant of all loads has an eccentricity of more

than one-sixth the width of the pier, tensile stresses will develop. It is desirable to avoid the possibility of tensile stresses, by relocating the pier with reference to the point of application of loads or redesigning the pier.

Piers are usually square in cross-section; if rectangular, the longer dimension is seldom more than 50 per cent greater than the shorter side. Typical cross-sections of piers are illustrated in Figs. 7-2 and 7-3.

A pilaster is built as part of a wall. It is bonded and otherwise constructed so as to be an integral part of the wall. Pilasters are located at points which support concentrated loads. The required cross-sectional area of a pilaster is determined in a similar manner to that used in the design of piers, dividing the total load by the allowable compressive stress. The required area may be provided in part by that section of the main wall immediately adjacent to the pilaster. The load on a pilaster is frequently eccentrically applied and sometimes there is a horizontal thrust. In such instances, the resultant pressure should be plotted graphically and the pilaster made sufficiently wide to keep the resultant reaction within the middle-third of any section. Typical pilaster construction and bonding methods are illustrated in Fig. 7-4.

An isometric view showing the use of clay tile bearing slabs for end construction hollow tile pilasters is shown in Fig. 7-5. Two or three brick courses or the equivalent height in solid masonry units are also often used to provide load distribution.

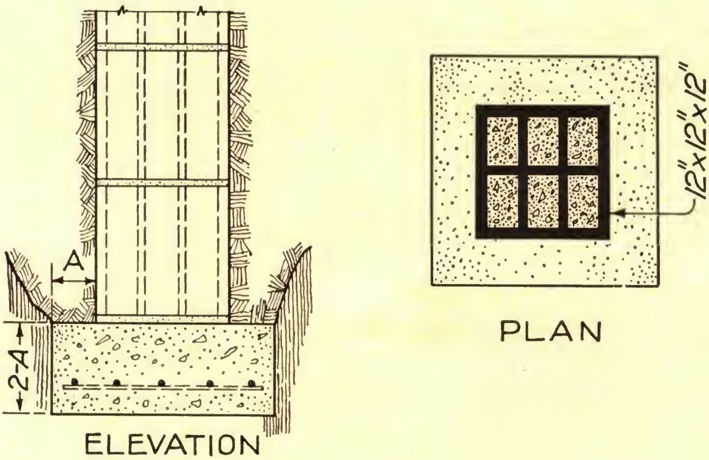


FIG. 7-3

Vertical cell structural clay tile pier with reinforced concrete footings. Cells may be filled with grout or concrete as shown and reinforcing steel added if desired.

A pilaster or buttress used to provide lateral support for a wall may fail by wholly or partially overturning or by one part sliding on an adjoining part at the joint between them. Both types of failure should be examined in the design.

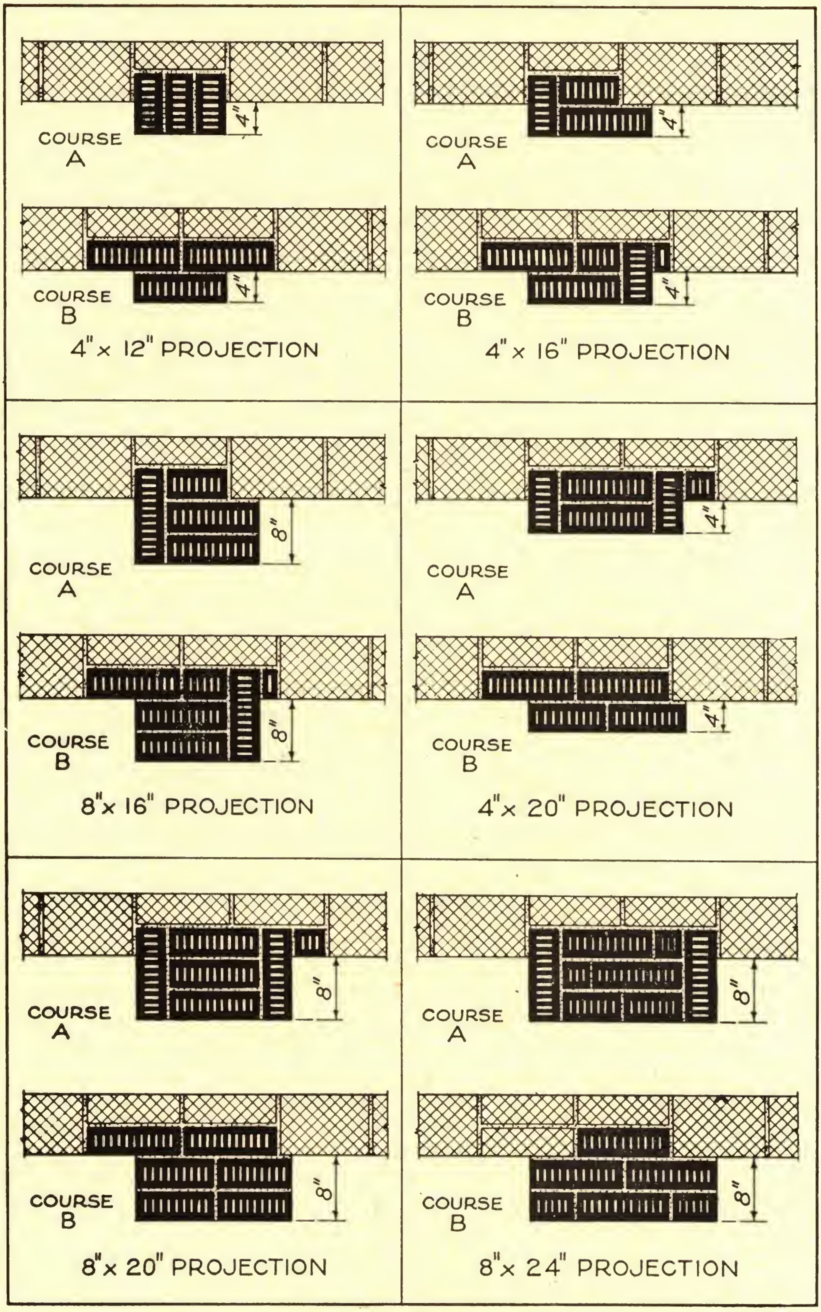


FIG. 7-4

Typical pilaster details showing the use of solid masonry units (25 per cent maximum voids) for high compressive strength requirements. Hollow units are similarly used where additional area is required for concentrated loads.

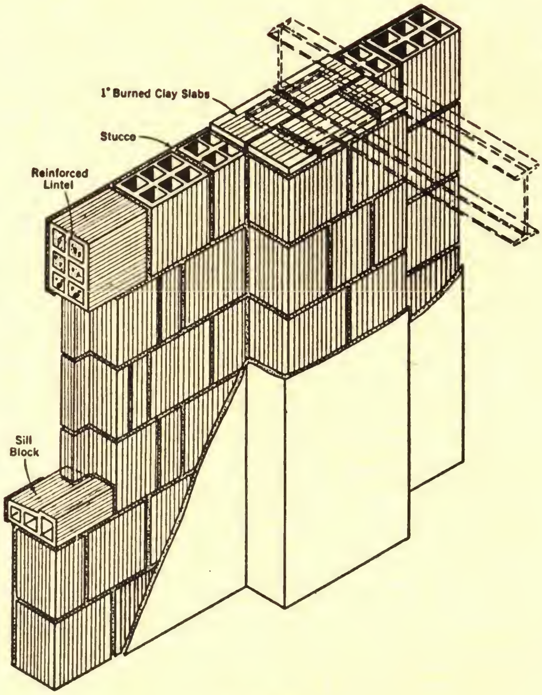


FIG. 7-5

Structural clay tile wall and pilaster detail showing the use of tile bearing slabs for vertical cell construction.

The resistance to sliding may be determined from the formula:

$$H = fW$$

where $H =$ sliding resistance to horizontal forces acting above the section
$f =$ coefficient of friction at plane of slippage
$W =$ weight plus any applied vertical load above plane of slippage.

The following coefficients of friction (f) may be used in design calculations:

Masonry on masonry	0.65
Masonry on moist clay	0.33
Masonry on sand	0.40
Masonry on gravel	0.60

The construction is stable against slipping, provided the value of H is equal to or greater than the sum of the horizontal components of the forces acting above the plane of slippage.

Stability against overturning is attained when the resultant reaction of all forces, through all sections and the base, falls within the middle third of the sections and base.

708. FOOTINGS

The purpose of a footing is to distribute the entire superimposed load of a structure over the bearing areas in such a manner as to equalize the pressure throughout. Unit pressure must not exceed the bearing value of the foundation bed and where the footings of a structure rest on sub-soils having the same supporting value, all the footings should transmit equal loads per square foot to the supporting sub-soil. If the bearing capacities of the supporting soils vary, the footings should be proportioned so as to distribute the unit loads with equal relation to the various maximum bearing values of the soil at each footing. There is usually some settlement in all buildings except those resting on rock. It is essential, therefore, that settlement be equal on all footings; otherwise the building will settle unevenly and, aside from uneven floors and walls out of plumb, cracks develop in walls and partitions while doors and windows bind in their frames.

Brick and tile have been widely used for footings on one- and two-story buildings, particularly residences, small store buildings and garages. Allowable compressive stresses for structural load-bearing tile in most building codes range from 70 to 85 psi which is equivalent to 10,000 psf for the lower value and 12,000 psf for the higher value. It is seldom that the actual load or weight of moderate size residences or store buildings would be sufficient to impose on the footings a unit load of more than 5000 psf.

Where the foundation walls are to be constructed of brick or tile, it is frequently desirable to use the same material for the footing since both footing and foundation can be built in one operation. As soon as the sub-grade is prepared, the mason places a bed of cement mortar, spread approximately 1 in. thick to take up irregularities in the sub-grade and starts laying the footing. In this manner, the footing is completed shortly after the preparation of the sub-grade, without the delays which normally accompany concrete footings.

There are places, however, where it may be advisable to use concrete footings, such as in locations having very irregular or uneven sub-bases necessitated by the removal of soft, spongy, filled or otherwise unstable sub-soil. Back-filling of all such excavations below normal sub-grade should be made with concrete having the proper consistency and compressive strength to insure durability and meet job requirements. It is then frequently convenient to construct the footings of plain or reinforced concrete as required.

In clay sub-soils subject to serious shrinkage cracks in dry weather or in sub-soils that may settle unevenly, the footings should be reinforced with longitudinal steel rods placed either in concrete or the lower mortar joints of the brick or tile footing. Reinforcing rods should be continuous all around the footing. It is customary to use three or four ⅜-in. rods with an overlap of approximately 15 in. The mortar joint containing the rods is made at least ¼ in. thicker than the diameter of the steel to insure complete coverage.

(a) Bearing Capacity of Soils. The bearing capacity of soils depends upon their composition, the degree to which they are confined and the amount of moisture which they contain. In the absence of test data on the bearing capacities of different foundation beds, the values given in Table 7-6 may be used as a guide.

Bearing values of various soils have been given to indicate their relative merits. These values have been used for years in localities where experience

TABLE 7-6

BEARING CAPACITIES OF VARIOUS SOILS

Foundation-bed	Tons per sq. ft.	Lb. per sq. ft.
Soft clay	1	2,000
Wet sand	2	4,000
Firm clay	2	4,000
Sand and clay, mixed or in layers	2	4,000
Fine, dry sand	3	6,000
Coarse, dry sand	4	8,000
Gravel	6	12,000
Soft rock	8	16,000
Hard-pan	10	20,000
Medium rock	15	30,000
Hard rock	40	80,000

has verified their accuracy within reasonable ranges of safe loading. There are many kinds and mixtures of soils, and it is not always possible to judge the safe bearing capacity of any given soil by mere reference to a load table. When there is any doubt, more accurate information should be obtained.

The most common method of checking the bearing capacity of a sub-soil is by means of borings and load tests.

Core borings are the most reliable but also most costly. They are taken in advance of a design of all important structures. The cores are accurate and may be measured and plotted to indicate sub-soil conditions for practically any depth desired.

For the average size building, the designer may obtain additional information regarding the bearing capacity of soils in any particular locality by conferring with the local building commissioner or contractors experienced with foundation work.

(b) Design. Footings are designed to carry all of the dead load and most of the live load. Many building codes permit a reduction in live load calculations for the design of columns, walls, piers and footings of buildings more than two stories in height. For buildings less than three stories in height, footings should be designed to carry the total dead and live load.

The total load of a structure is distributed over piers, columns and walls. It is necessary, therefore, to calculate the amount of load carried to each pier, column, or lineal foot of wall.

The required area of the footing is determined by dividing the total load to be supported by the allowable bearing capacity of the supporting soil. Column or pier footings are either square or rectangular, depending upon the shape of the structural member. Wall footings are determined from the total load per lineal foot of wall. Since the dimensions parallel to the wall is 12 in., the other dimension necessary to make the required area will be at right angles to the wall, or width of footing.

The increase in size of footings over that of the column, pier or width of wall is obtained by offsets or stepping (pyramiding) the base of the column, pier or wall out to the required dimension. Stepping or pyramiding is done by offsetting each course. The maximum projection of the offset of one unit should not exceed one-half the depth of the unit nor one-third its width at

right angles to the face which is offset. The total projection of a footing should be not more than one-half of its depth unless reinforcement is provided to resist bending.

Example of wall footing: Determine width of a footing under a foundation wall 16 in. thick carrying a load of 12,000 lb. per lin. ft. Sub-soil is a fine, dry sand.

Referring to Table 7-6, it is noted that fine, dry sand has a bearing capacity of 6,000 psf. Required area of footing is $12{,}000/6{,}000 = 2$ sq. ft. Since the load is given per lineal foot of wall, the footing will be made 24 in. wide in order to provide a bearing area of 2 sq. ft.

Example of pier footing: A square pier carries a concentrated load of 50,000 lb.; the supporting soil is coarse, dry sand. Allowable soil pressure is 8,000 psf. Required area of the footing will be $50{,}000/8{,}000 = 6.25$ sq. ft. One side of the square footing will be $\sqrt{6.25} = 2.50$ ft. $= 30$ in.

In locations subject to freezing temperatures, footings should be carried below the frost line in order to avoid disturbance from the freezing and thawing of the foundation material.

Alternate wetting and drying disturb most soils. It is essential, therefore, that the footings be placed at a reasonable depth whether or not there is frost action. Most local building codes stipulate a minimum depth for footings.

709. FOUNDATIONS

Foundation walls usually serve both as bearing and retaining walls. As bearing walls, they support the superstructure of buildings which, with the exception of unusually eccentric loads, produce compressive stresses in the foundation. As retaining walls, they support the earth backfill against one side. The stability of foundation walls, therefore, depends upon their resistance to the vertical loads and the lateral earth pressures, and upon their durability.

Compressive stresses in foundation walls, produced by the vertical loads, can be readily determined and should not exceed the allowable compressive working stress permitted in the local building code. It will be found, however, that the calculated unit compressive stress, in most instances, will be only a fraction of the permissible compressive stress, due to the minimum thickness requirements for walls with relation to the height of the structure.

The resistance of a masonry foundation wall to lateral earth pressure is usually a more vital factor than its resistance to the vertical loads. A stress analysis of a foundation wall, regardless of the assumptions as to the manner of support, will, as a rule, indicate that the lateral earth pressure produces tensile stresses in the wall. Most structures are designed on the assumption that plain (unreinforced) masonry is incapable of resisting tensile stresses. The fallacy of this assumption is apparent in view of the fact that there are innumerable masonry foundations which for years have successfully resisted such theoretical or actual tensile stresses. It is probable, however, that the actual tensile stresses are less severe than the calculated stresses, because the latter are frequently based upon assumptions as to soil pressures which are not realized.

An important feature which many building code writers have apparently overlooked is the fact that under normal conditions the greater the vertical load on a foundation wall, the greater its stability. Frequently building code

regulations require the use of thicker foundation walls under masonry buildings than lighter types of superstructures. There is no justification for this requirement. Actual analysis of two foundation walls with all conditions identical, except that the superstructure in one case is frame construction while the other is of masonry, will indicate that the stability of the foundation under the masonry superstructure is greater than the foundation supporting the lighter frame superstructure.

(a) Conventional Requirements. The following sections, quoted from the American Standard Building Code Requirements for Masonry, A41.1-1944, are typical of modern building code requirements and conform to current good practice. For average conditions, designs based upon these requirements will *be both* economical and safe.

1. Foundation walls shall be of sufficient strength and thickness to resist lateral pressures from adjacent earth and to support their vertical loads without exceeding the stresses specified in Section 3, Allowable Stresses in Masonry; provided, that in no case shall their thickness be less than the walls immediately above them, except as provided in Section 2-3.

2. Foundation walls shall be of not less than 12-in. nominal minimum thickness, except as follows:

(a) Solid masonry walls reinforced with at least one ⅜-in. round deformed bar, continuous from footing to top of foundation wall, for each 2 ft. of length of the wall, may be of 8-in. nominal thickness.

(b) Solid foundation walls of solid masonry units or of coursed stone that do not extend more than 5 ft. below the adjacent finished ground level, and hollow walls of masonry and walls of hollow units that do not extend more than 4 ft. below the adjacent finished ground level, may be 8 in. in nominal minimum thickness. These depths may be increased to a maximum of 7 ft. with the approval of the building official when he is satisfied that soil conditions warrant such increase. The total height of the foundation wall and the wall supported shall not exceed that permitted by these requirements for 8-in. walls.

(c) Foundation walls of rubble stone shall be at least 16 in. thick. Rough or random rubble without bonding or level beds shall not be used as foundations for walls exceeding 35 ft. in height, nor shall coursed bonded rubble walls be used as foundations for walls exceeding 50 ft. in height.

(d) Foundation walls of cast-in-place concrete shall be at least 8 in. thick; provided that when supporting one-story structures, and the area within the foundation walls is not excavated, they may be 6 in. thick if the total height of the foundation wall and the wall supported is within the allowable height of 6-in. walls.

3. Foundation walls of 8-in. nominal thickness and conforming to the provisions of this section may be used as foundations for single-family dwellings with walls of brick veneer on frame walls, or with nominal 10-in. cavity walls, provided that the dwelling is not more than 1½ stories in height and the total height of the wall, including the gable, is not more than 20 ft. Foundation walls of 8-in. nominal thickness supporting brick veneer or cavity walls shall be corbelled with solid units to provide a bearing the full thickness of the wall above. The total projection shall not exceed 2 in. with individual corbels projecting not more than one-third the height of the unit. The top corbel course shall be not higher than the bottom of floor joists and shall be a full header course.

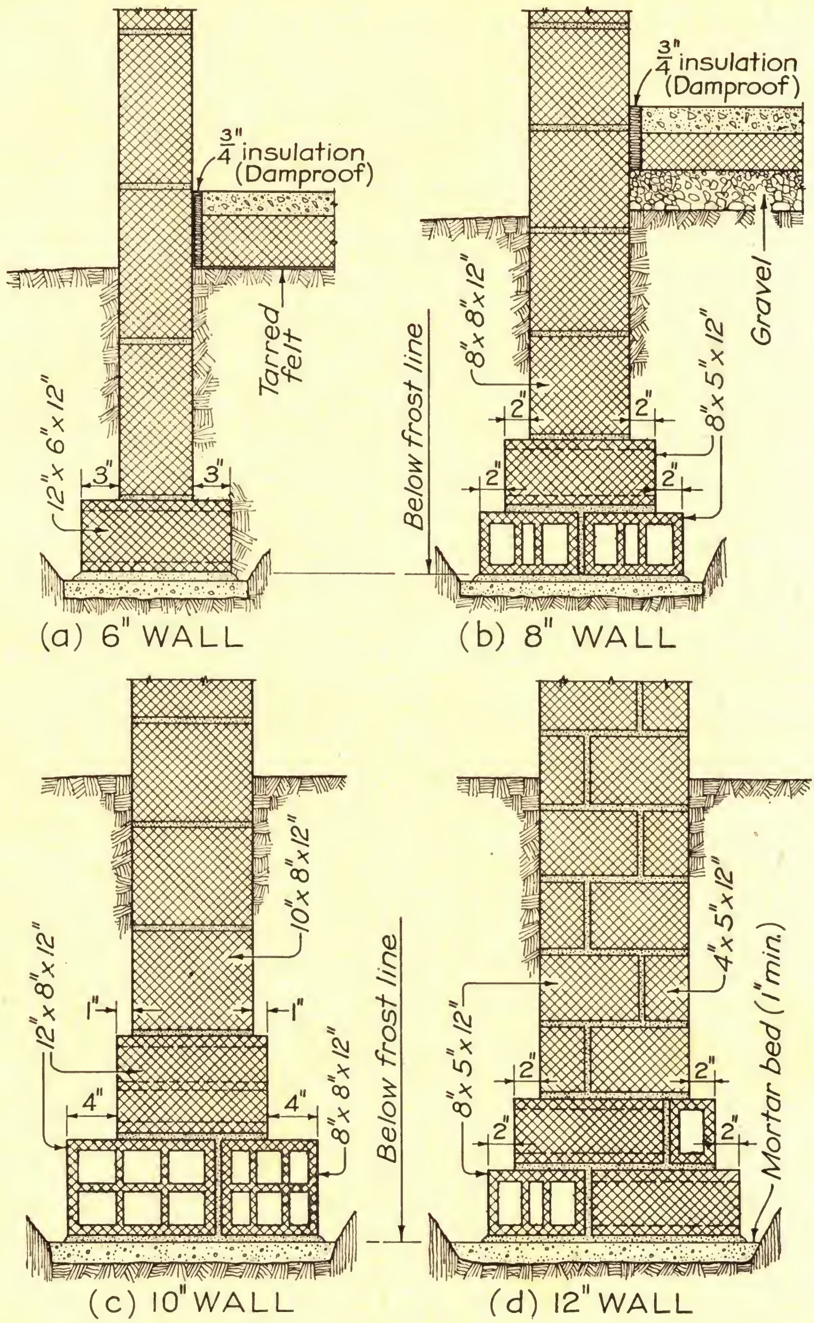


FIG. 7-6

Typical structural clay tile foundation walls and footings.

4. Foundation walls shall extend below the level of frost action.

Figs. 7-6 and 7-7 show typical brick or tile foundation walls conforming to the requirements of the American Standard, A41.1-1944.

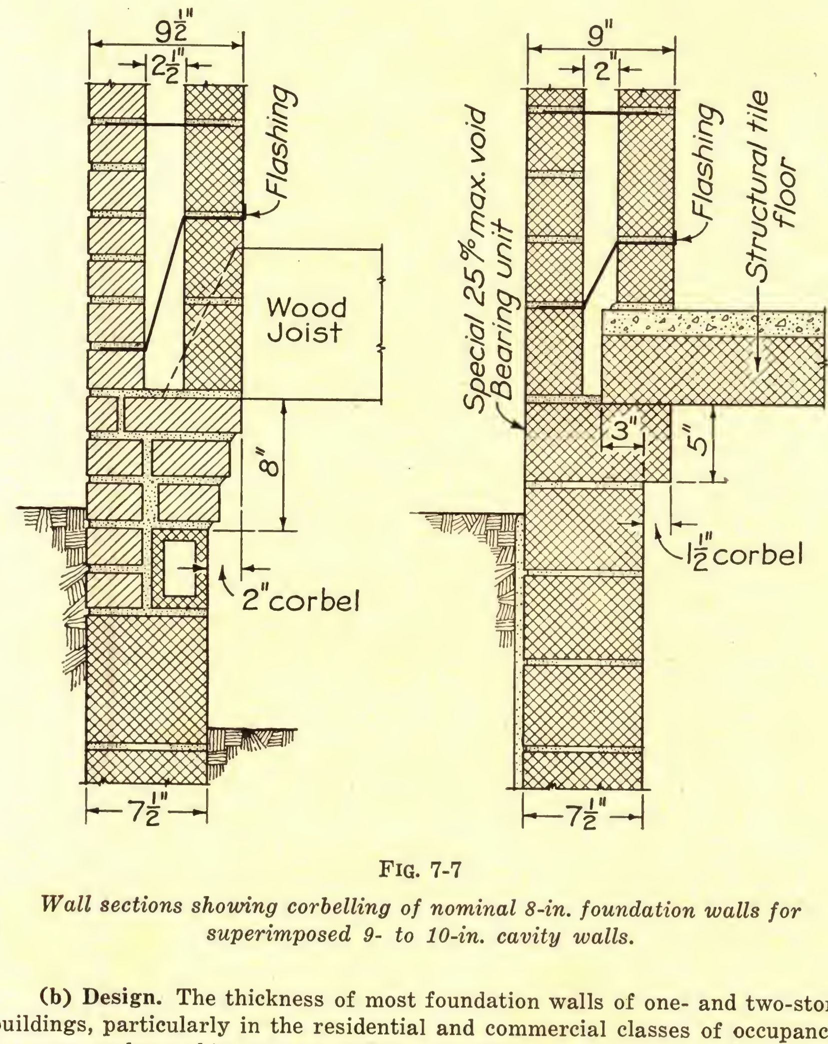


FIG. 7-7

Wall sections showing corbelling of nominal 8-in. foundation walls for superimposed 9- to 10-in. cavity walls.

(b) Design. The thickness of most foundation walls of one- and two-story buildings, particularly in the residential and commercial classes of occupancy, are more or less arbitrarily fixed by local building regulations.

These thicknesses are based on the results of experience with existing structures. There are occasions, however, when it is desirable to design such a foundation by theoretical analysis. This is done by assuming a wall thickness which approximates conventional requirements and then analyzing it to determine maximum stresses and their location.

In the absence of other data, structural clay tile masonry may be assumed as weighing 55 pcf, brick masonry 120 pcf, and the earth pressure as equivalent to that produced by a liquid weighing 10 to 30 pcf. Lower values for

earth pressure are used where the soil is firm, cohesive and well-drained, while the higher values are assumed for wet or saturated soils.

Vertical loads from the roof, floors and walls are determined, as well as their point of application on the foundation wall. The weight of the foundation wall itself should be considered as acting through its center of gravity. Lateral pressure on the wall produced by the earth backfill varies from zero at the surface to a maximum at the base. If "w" represents the weight in pounds per cubic foot of the equivalent fluid and "h" is the height of backfill in feet, the lateral pressure at the base in pounds per square foot is "wh" and the total resultant earth pressure, in pounds per lineal foot, is $\frac{wh^2}{2}$. This pressure may be considered as applied horizontally to the wall at one-third the height of the backfill from the bottom.

All of these forces are considered in calculating the moments at various points in the foundation. There are, however, different conditions of support and continuity of the foundation wall which should be considered and which will have varying effects on the calculated stresses. The following arbitrary assumptions as to manner of support and continuity cover most conditions within which the actual construction will fall:

(1) The wall is considered as a slab supported at the footing and first floor; neglecting the lateral supporting effect of end walls, piers, cross walls, etc.

(2) Same as (1), except that the wall is assumed as fixed at the footing;

(3) Same as (1), except that the wall is assumed as continuous in a vertical direction at the first floor line;

(4) The wall is considered as a vertical slab panel, simply supported at the four edges; at the footing and first floor and by end walls, piers or cross walls;

(5) Same as (4), except that the wall panel is assumed as fixed at the footing;

(6) Same as (4), except that the wall panel is assumed as continuous in a vertical direction at the first floor line.

There are other possible combinations of assumptions regarding the degree of fixity at the footing and continuity with adjoining masonry at other supports, but the above six conditions will as a rule afford a complete study.

Of course, design analyses are made for only as many of the six conditions as might apply to a particular foundation wall. The first (1) is probably the most severe and computations based on those assumptions will usually indicate greater tensile stresses than those resulting from any of the other five assumed conditions.

The maximum computed stress will occur at the point of maximum moment. This critical point may be found by plotting the moment curve for each of the six conditions. However, it may not be necessary to plot the moment curves, except in the analysis of an unusual foundation design. The location of the critical point or points is influenced by the amount and location of both vertical and lateral loads. In most foundation designs, it will be found that the maximum tensile stress occurs at the inside face approximately mid-height of the backfill for studies based on assumptions (1), (3), (4) and (6). For studies (2) and (5), the maximum tensile stress will in all probability

be at the outside at the top of the footing. In studies (3) and (6), the moment should also be calculated at the outside face opposite the first floor.

Inasmuch as the assumed conditions (4), (5) and (6) consider the wall as a rectangular slab supported at the four edges, the critical points are analyzed for moment in both the vertical and horizontal direction. All of the vertical loads may be taken into consideration in the determination of moment for the vertical element. Lateral earth pressure, however, may be considered

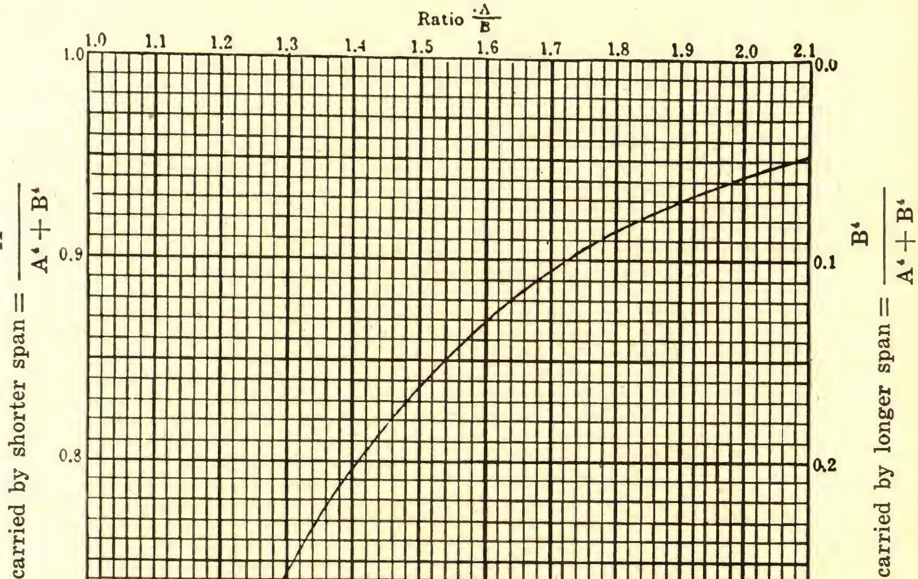


FIG. 7-8

Curve showing distribution of load for rectangular slabs supported at the four edges.

as distributed in both vertical and horizontal directions. The proportion of the load or pressure carried by the vertical element is $\frac{H^4}{H^4+V^4}$; where V is the vertical dimension (height) of the wall panel and H is the horizontal dimension between supports. In a like manner, the proportion of the load carried in the horizontal direction is $\frac{V^4}{H^4+V^4}$. The sum of the two should equal the total load or pressure.

Fig. 7-8 which shows the proportionate distribution of loads for rectangular slabs supported on four edges may be used to determine these pressures.

The resultant stress at any point is not the sum of the two stresses due to vertical and horizontal moments. In fact, according to the theory of Poisson's ratio for lateral strains, axial stresses of the same type tend to decrease the resultant stress at a point. However, to be on the safe side, if the computed stresses in both horizontal and vertical directions are of the same kind, it is recommended that the greater of the two be considered as the resultant maximum stress.

Moments are taken about any point in question and the corresponding stress at that point is then determined by means of the equation:

$$S = \frac{6M}{bd^2} \quad \dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Where, S = stress in pounds per square inch at the extreme fiber,
M = computed moment in inch-pound,
d = thickness of wall in inches and
b = width of unit section in inches (12 in.).

The resultant compressive or tensile stress may be determined from the formula:

$$f = S \pm P/A \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

Where, f = resultant stress in pounds per square inch
S = the bending stress in pounds per square inch; formula (1)
P = vertical loads in pounds
A = area of wall section (12 in. long) in square inches.

The plus sign is used to determine maximum compressive stress and the minus sign for maximum tensile stress.

It is seldom that the compressive stress will be a matter of concern, but cognizance should be given to any indication of tensile stresses. If the latter are found to be excessive, the wall should be redesigned to increase its stability by reinforcement, additional thickness or less distance between supports.

Figs. 7-9, 7-10 and 7-11 show the relation between maximum tensile stresses and the height of backfill for foundation walls 8 in. and 12 in. thick supporting one-story houses with frame and masonry exterior walls. These stresses were determined for each of the six assumptions as to manner of support listed in this section and for the following assumed loads:

Weight of masonry wall above foundation............590 lb./lin.ft.
Weight of frame wall above foundation................ 96 lb./lin.ft.
Weight of floor load and partitions..................100 lb./lin.ft.
Weight of roof.. 40 lb./lin.ft.
Lateral pressure of earth equivalent to that
produced by liquid weighing......................... 20 lb./cu.ft.

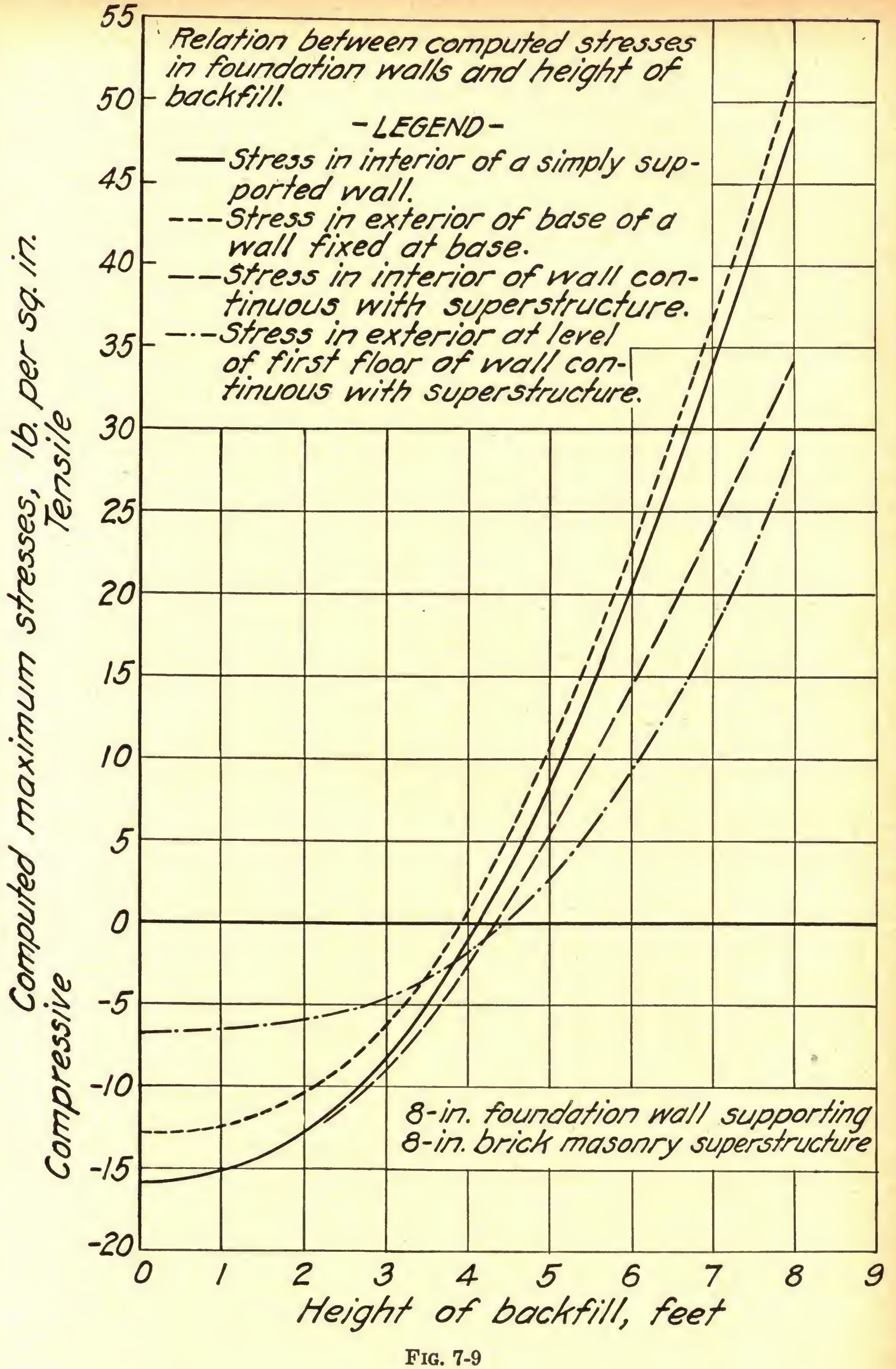

Relation between computed stresses in foundation walls and height of backfill.
-LEGEND-
——Stress in interior of a simply supported wall.
---Stress in exterior of base of a wall fixed at base.
— —Stress in interior of wall continuous with superstructure.
-·-Stress in exterior at level of first floor of wall continuous with superstructure.
8-in. foundation wall supporting 8-in. brick masonry superstructure
Computed maximum stresses, lb. per sq. in.
Tensile
Compressive
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
0
1
2
3
4
5
6
7
8
9
Height of backfill, feet

FIG. 7-9

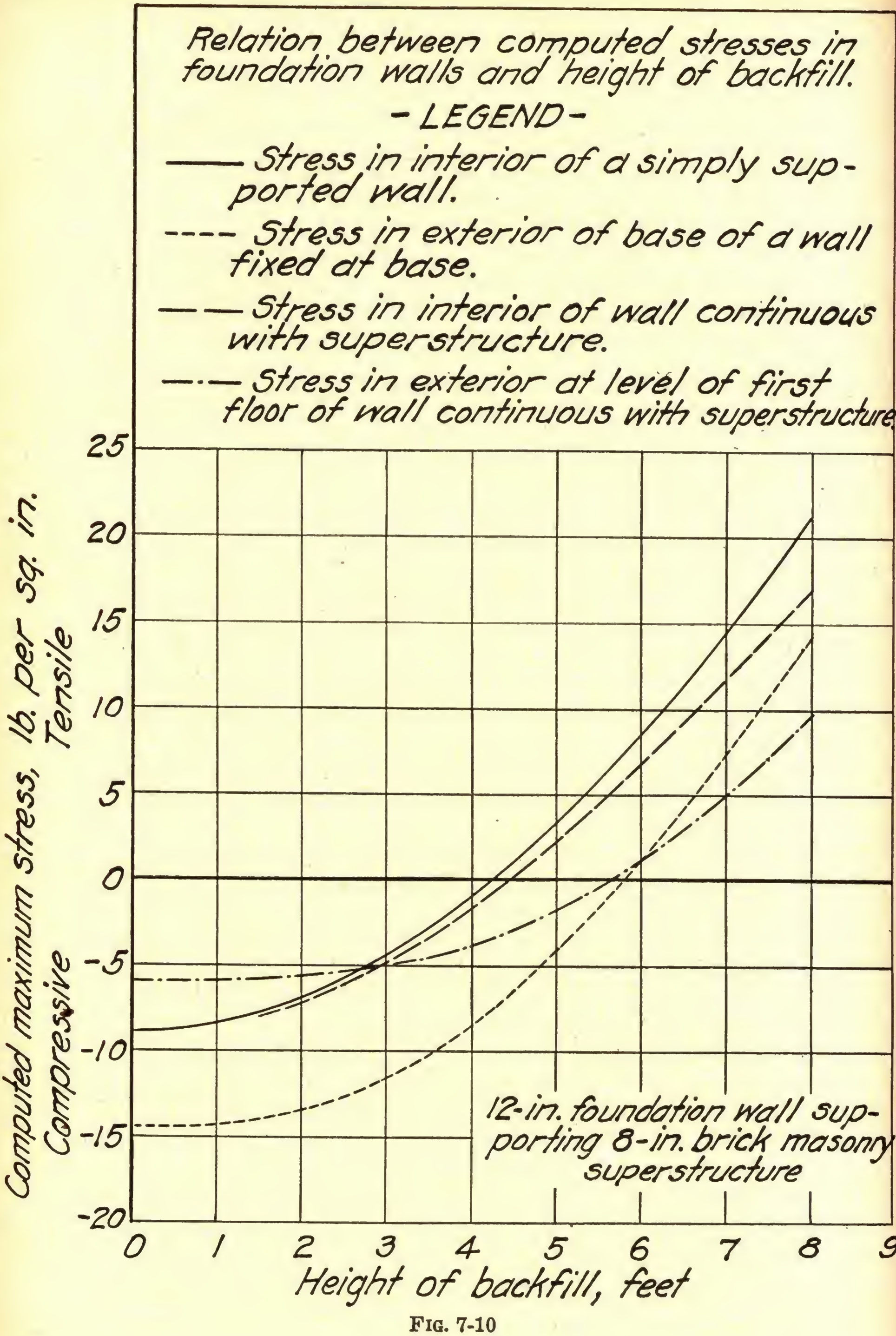
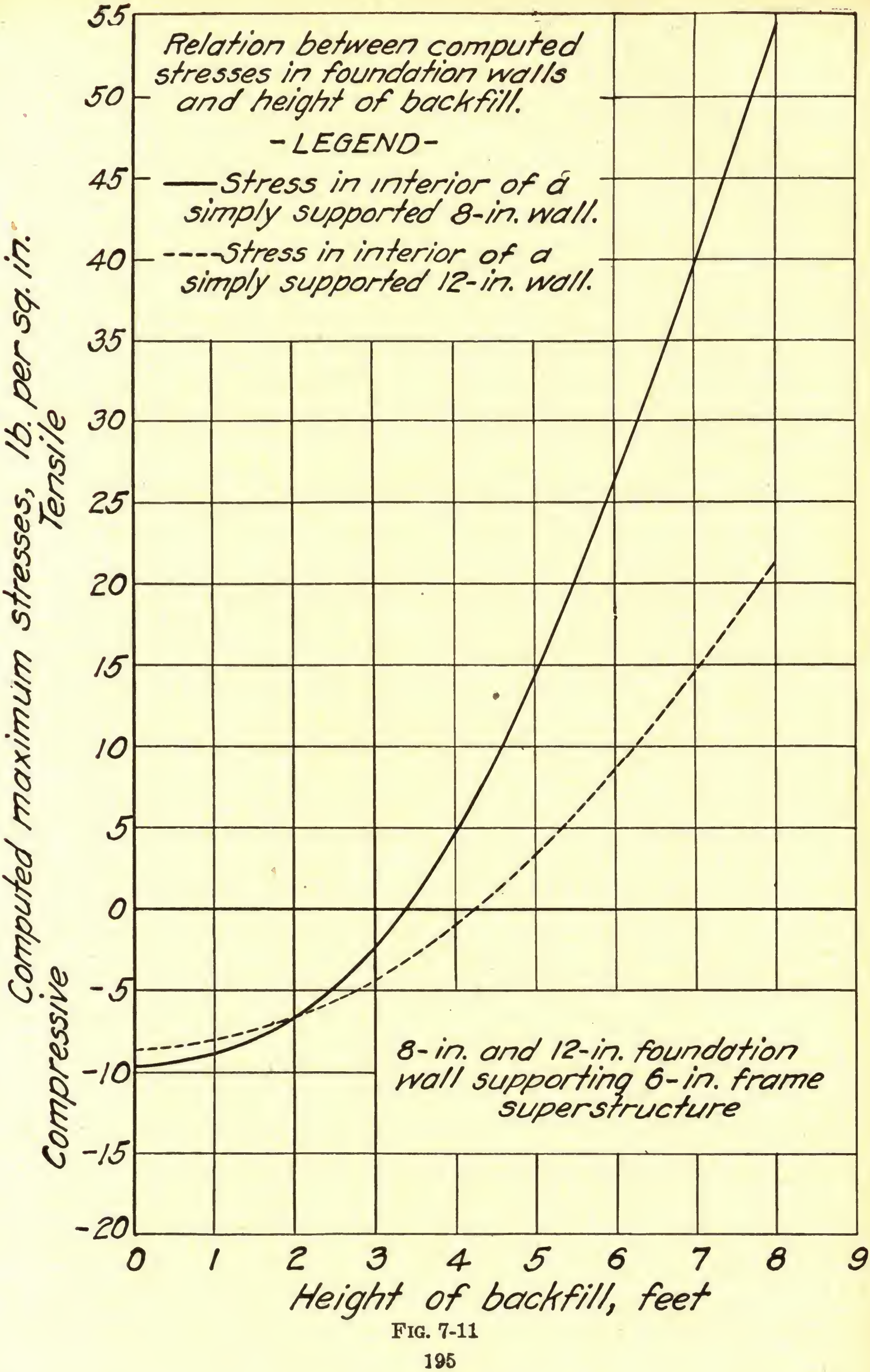

Relation between computed stresses in foundation walls and height of backfill.
- LEGEND -
Stress in interior of a simply supported wall.
Stress in exterior of base of a wall fixed at base.
Stress in interior of wall continuous with superstructure.
Stress in exterior at level of first floor of wall continuous with superstructure.
Computed maximum stress, lb. per sq. in.
Tensile
Compressive
25
20
15
10
5
0
-5
-10
-15
-20
0
1
2
3
4
5
6
7
8
9
Height of backfill, feet
12-in. foundation wall supporting 8-in. brick masonry superstructure

FIG. 7-10


Relation between computed stresses in foundation walls and height of backfill.
-LEGEND-
——Stress in interior of a simply supported 8-in. wall.
----Stress in interior of a simply supported 12-in. wall.
8-in. and 12-in. foundation wall supporting 6-in. frame superstructure
Computed maximum stresses, lb. per sq. in.
Tensile
Compressive
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
0
1
2
3
4
5
6
7
8
9
Height of backfill, feet
FIG. 7-11

The vertical loads assumed as acting on the foundation are very low and are comparable to those to which a foundation under a one-story single-family residence might be subjected.

The graphs show the stresses at the sections of greatest bending moment. For walls simply supported at top and bottom, the maximum tensile (or minimum compressive) stress was at the inside face near mid-height of the backfill. With the base fixed, it was at the outside face at the footing level. For walls considered to be continuous with the superstructure, this maximum stress was at the inside face near mid-height of the backfill, although there was also a relatively large stress in the outside face at the first floor level for both the 12- and 8-in. foundation walls.

The maximum tensile stresses in the foundation walls with brick masonry superstructure are less than in the foundation walls with frame superstructure, as can be seen by comparing Fig. 7-9 and 7-10 with Fig. 7-11. For the 8-in. foundation walls simply supported at the footing and first floor levels, the maximum tensile stress is 6 psi less with the heavier superstructure for the maximum height of backfill. The addition of another story on the dwelling with exterior walls of brick would decrease the maximum tensile stress in an 8-in. foundation wall at mid-height on the inside face by approximately 9 psi and about 6 psi in the outside face at the footing level.

(c) Drainage and Waterproofing. The following statement regarding the importance of drainage is included in the 1940 Report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete, and applies with equal force to unit masonry structures:

"Too much emphasis cannot be placed on the need for drainage around the structure where unsightliness or damage will result from the penetration of water. In many cases, proper drainage would be all that is needed to preserve the structure or to protect the interior. In the opinion of this committee, drainage should be considered not as an adjunct to waterproofing, but rather as a first requirement to which waterproofing is added as a further protection."

Except in well-drained soil, usually sandy or gravelly, it is advisable to place drain tile near the bottom of exterior basement walls, foundations and footings. In most instances, drain tile with plain ends or vitrified sewer pipe with or without bells of 4-in. to 6-in. diameter will suffice. The drain should be laid with a slope of not less than ⅛ in. per ft., preferably keeping the high point below the elevation of the basement floor, with the low ends of the drain at approximately the same grade as the bottom of the footing.

This drain tile should be carefully laid on firm even bearing with no traps. If drain tile are used, the ends should be butted together and in no case more than ¼ in. apart. The top half of the joints should then be covered with a strip of copper mesh or building paper approximately 4 in. wide before the backfill is placed. If vitrified sewer pipe is used, the spigot end should be placed in the bell up to the shoulder and a strip of jute, hemp or burlap caulked around the bottom of the spigot in order to center it in the bell and provide a straight flow line. It will be necessary to excavate small holes below the grade line of the trench to receive the bells of this type of pipe and provide the main bearing along the straight stem. The bell end of the pipe should be set facing the up-grade.

Drains around the foundations of a building are usually in two parts or systems, meeting at a common low point and then carried into or connected

with a drainage outlet. This drainage outlet, including the wye, bends and other specials should be of vitrified tile.

An ideal fill over the foundation drain tile is one composed of coarse gravel or stone at the bottom, grading through medium to sand near the top. Backfill for the first couple of feet above the tile should be carefully placed, not dumped, to avoid breaking the tile.

The outside of foundation walls below grade should be parged from the bottom of the footing to several inches above the grade line. This pargeting, composed of 1 part portland cement, ¼ part lime putty and 3 parts of well graded sand by volume, should be troweled on at least ½ in. thick to an even smooth surface with coves of not less than 2-in. radius at each offset in the footing.

In wet soils, it is also advisable to add a coating of bituminous waterproofing. For absolutely watertight jobs, three or more layers of cotton fabric are bonded to the wall with asphalt or coal tar pitch applied hot. This is called membrane waterproofing. Bituminous coatings should be continuous from the finish grade line to the top of the footing and should be applied when the wall is dry.

A further precaution, recommended to prevent dampness from rising by capillarity in the foundation wall, is to place a damp-check in the mortar joint at the top of the footing. This damp-check may be composed of any suitable flashing material. Through-wall flashing should also be placed in the wall at approximately the third mortar joint above grade unless the units are designed to carry seepage water directly to the foundation drainage system or to the house sewer outlet below the basement floor. Termite shields, which also act as damp-checks, are recommended as a precautionary measure if wood joist or studs are used in the construction. They are usually placed directly below the joist bearing and, if properly carried through the wall, may replace the flashing ordinarily required between the grade line and first floor.

For a further discussion of dampproofing and waterproofing, see Section 716.

(d) Hollow Foundation Walls. Hollow walls of solid masonry units or cavity walls of brick or tile have been used successfully as foundation walls for residential and small commercial structures where working stresses are not exceeded and conditions of stability are satisfied. In the construction of such walls, provision is made to drain any water which may enter the wall to the footing drain and, while in many localities this will prevent moisture from penetrating the wall, it is recommended that the same precaution regarding waterproofing of solid walls be applied to hollow walls.

In areas where condensation on basement walls is a problem, the air space in the hollow wall which provides insulation between the warm air in the basement and the ground will reduce condensation.

710. SUPPORT OVER OPENINGS

The dead weight of a masonry wall which must be supported over openings can safely be assumed as the weight of a triangular section whose height is one-half of the clear span of the opening. Arching action of the masonry above the top of the opening may be counted upon to support the additional weight. A concentrated load over an opening may be distributed along a wall length equal to the base of the triangle whose sides make an angle of 30 degrees with the vertical from the point of application of the concentrated load.

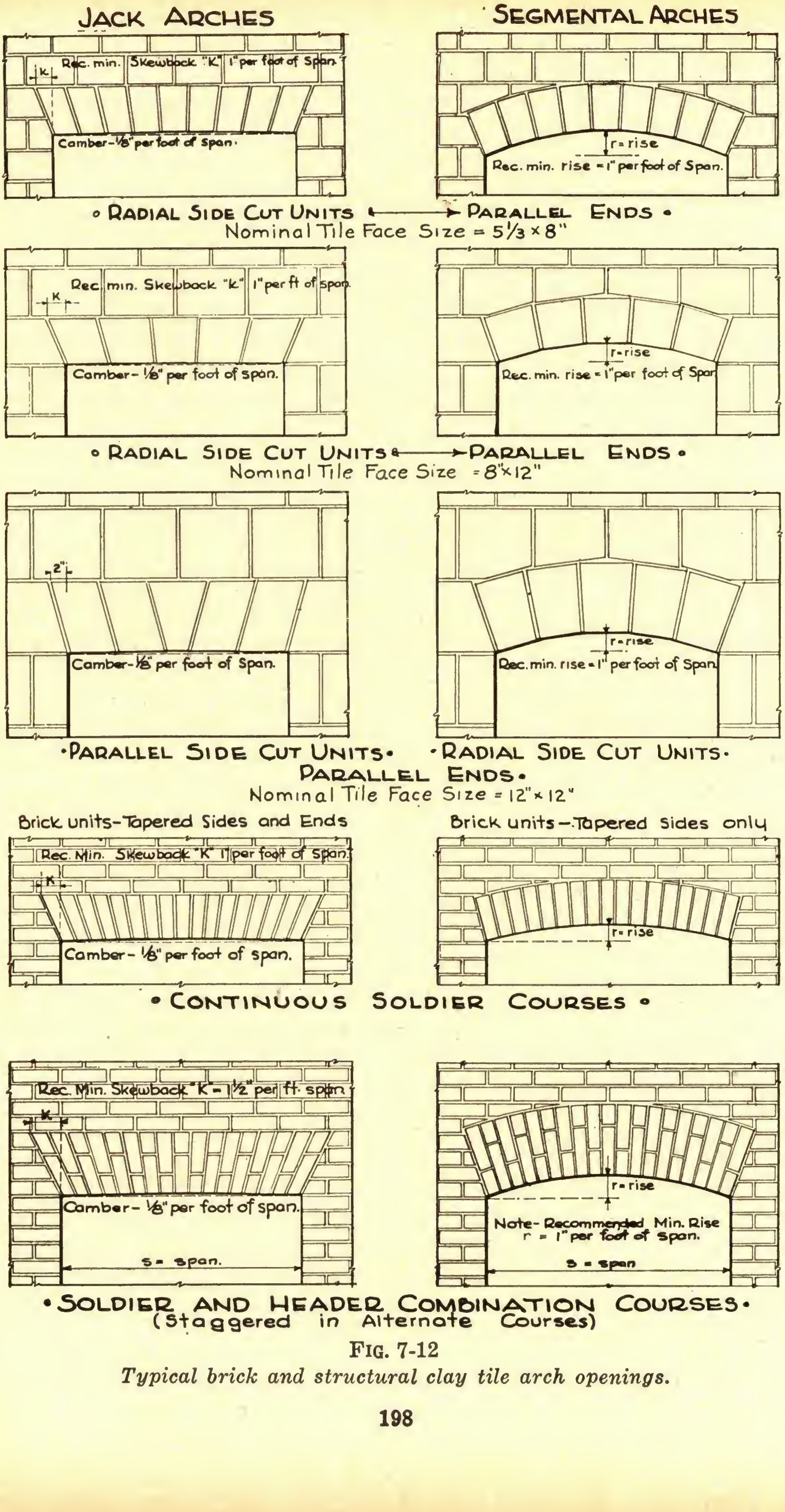


FIG. 7-12

Typical brick and structural clay tile arch openings.

In the past, the most common method of supporting masonry over openings was by steel angles or structural shapes; however, current (1950) practice increasingly favors reinforced brick or tile masonry. Various forms of segmental and flat arches are also used to span openings. Stresses developed in supporting members and the reactions at supports, or in the case of arches at the haunches, are determined by the common methods of design described in standard works on structural engineering.

Supports over door and window openings are referred to as lintels and are usually of relatively short span (3 to 6 ft.). Both segmental and jack (flat soffit) arches may safely be designed by empirical formulae for these short spans. A common rule for segmental arches 8 in. and 12 in. deep is to build them with a rise of 1 in. for each foot of span. The thrust at the spring line for uniform loading may be determined approximately by use of the following formula:

$$H = \frac{Ws}{8r}$$

Where H = horizontal thrust in pounds,
W = total uniformly distributed load in pounds,
s = clear span in feet,
r = rise of arch in feet.

For a concentrated load at the center of the arch, the thrust will be twice as great.

The common rule for jack arches is to provide a skewback of 1 in. per ft. of span for arches 8 in. deep and 1½ in. per ft. of span for 12-in. deep arches, also to construct the arches with a camber of ⅛ in. per ft. of span.

Fig. 7-12 shows typical designs of brick and tile segmental and jack arches, and Fig. 7-13 shows typical reinforced brick masonry lintels.

The following provisions relating to lintels and arches are quoted from the American Standard Building Code Requirements for Masonry, A41.1-1944:

"The masonry above openings shall be supported by arches or lintels of metal or masonry, plain or reinforced, which shall bear on the wall at each end for not less than 4 in. Stone or other non-reinforced masonry lintels shall

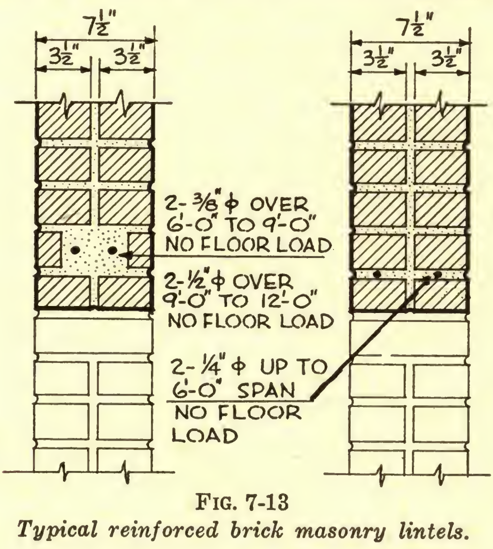


FIG. 7-13
Typical reinforced brick masonry lintels.

not be used unless supplemented on the inside of the wall with iron or steel lintels or with suitable masonry arches or reinforced masonry lintels carrying the masonry backing.

"Steel or reinforced masonry lintels shall be of sufficient strength to carry the superimposed load without deflection of more than 1/360 of the clear span.

"Masonry arches shall have at least 1-in. rise for each foot of span and shall be designed to carry the superimposed load. Proper provision shall be made for resisting lateral thrust."

711. PARAPETS

Field observations of parapet walls have disclosed cracks which in some instances may be attributed to expansion, either of the parapet wall or the roof slab. It is recommended, therefore, that all parapet walls be reinforced

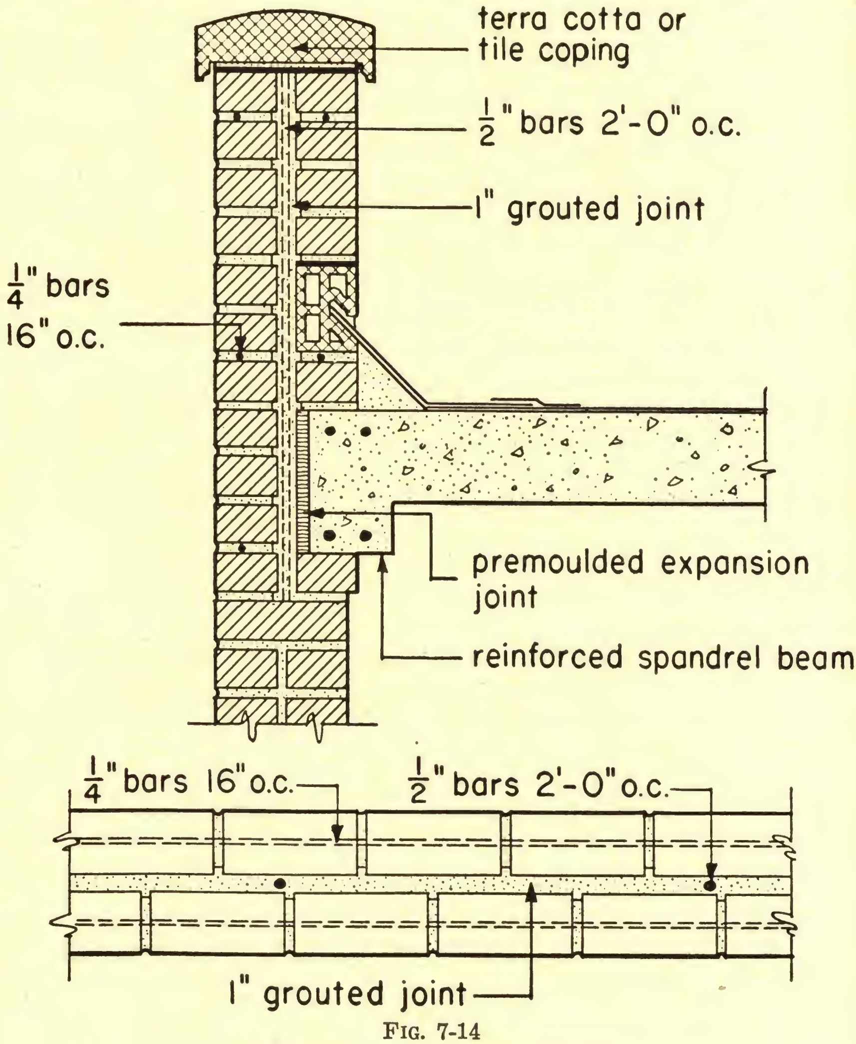


FIG. 7-14

Reinforced brick masonry parapet.

both horizontally and vertically with a minimum of ¼-in. round rods horizontally on 16-in. centers and ⅜-in. round rods vertically on 24-in. centers.

Due to the severe exposures to which parapets are subjected, special precautions should be taken to prevent the masonry from becoming saturated. Recommended flashings for parapets are given in Section 714, and, as indicated, *the practice of plastering the backs of parapets with a cement mortar or bituminous coating is not recommended.*

The quality of brick or tile used in parapet construction should be given careful consideration. *The back of the parapet wall should be built of the same well-burned grade of material as used for the facing. The common practice of using anything for this purpose that may be left on the job should be prohibited, since it is frequently the cause of rapid deterioration and failure of the wall resulting in costly repairs.*

Fig. 7-14 shows a reinforced brick masonry parapet with slightly more than the minimum reinforcement.

The following provision relating to parapet walls is quoted from the American Standard Building Code Requirements for Masonry, A41.1-1944:

"Parapet walls shall be at least 8 in. in nominal thickness. They shall be not higher than four times their thickness unless laterally supported; provided that when reinforced both horizontally and vertically with not less than ¼-in. rods spaced not more than 2 ft. on centers, the height shall be not more than six times the thickness. All parapet walls shall have a coping of incombustible material."

Copings should be provided on all parapet walls and since the mortar joints in the coping are most vulnerable to penetration of moisture, they should be kept to a minimum. Most effective copings are clay tile with bell and spigot or dove-tailed joints, or a copper covered precast concrete coping in which all joints in the copper covering are welded. The coping should overhang the parapet on both sides by a minimum of 1 in. and should provide a drip. If, for architectural reasons, it is undesirable to provide an overhang on the face of the wall, the overhang and drip should be provided at the back and the top of the coping should slope from front to back.

712. MISCELLANEOUS REQUIREMENTS

(a) Anchorage. Where there is a possibility that forces may be applied to walls, columns or roofs which may cause them to be lifted from their supports, such members should be anchored.

Anchorage of walls to foundations usually will be found necessary in buildings of light occupancy subject to winds of high velocity (exceeding 80 mph).

An investigation of the anchorage requirements should be made when designing buildings of less than four stories if the height is greater than twice the least width and for higher buildings when the height is greater than three times the least width.

Most building codes require all frame roofs to be securely anchored to the supporting walls. On masonry walls this anchorage may be provided by ½-in. bolts embedded not less than 2 ft. in the masonry and spaced 8 ft. on centers. Similar anchorage to masonry foundations should be provided for frame walls of residential structures not over two stories in height.

(b) Corbeling. Corbeling consists of off-setting successive courses of brick masonry outward from the face of the wall. This may be done for

architectural effects or to provide supports for structural members. Empirical rules limiting the maximum projection of corbels are based on experience and vary slightly in different building regulations.

The following is recommended for masonry other than chimneys: The maximum corbeled horizontal projection beyond the face of a wall shall be not more than one-half the wall thickness and the maximum projection of one unit shall not exceed one-half the depth of the unit nor one-third its width at right angles to the face which is off-set.

The recommended limitations on corbeling of chimneys are those included in the 1949 edition of the National Building Code recommended by the National Board of Fire Underwriters, as follows:

"No chimney shall be corbeled from a wall more than 6 in. nor shall a chimney be corbeled from a wall which is less than 12 in. in thickness unless it projects equally on each side of the wall; provided that in the second story of two-story dwellings corbeling of chimneys on the exterior of the enclosing walls may equal the wall thickness. In every case the corbeling shall not exceed 1-in. projection for each course of brick projected."

The "brick" referred to in the last sentence of the above is 2¼ in. thick.

The following paragraphs, (c) to (e), inclusive, are quoted from the American Standard Building Code Requirements for Masonry, A41.1-1944:

(c) Bonding of Wall Intersections. "Masonry walls shall be securely anchored or bonded at points where they intersect and where they abut or adjoin the frame of a skeleton frame building.

"When two bearing walls meet or intersect and the courses are built up together, the intersections shall be bonded by laying in a true bond at least 50 per cent of the units at the intersection.

"When the courses of meeting or intersecting bearing walls are carried up separately, the perpendicular joint shall be regularly toothed or blocked with 8-in. maximum off-sets and the joints provided with metal anchors having a minimum section of ¼ in. by 1½ in. with ends bent up at least 2 in., or with crosspins to form anchorage. Such anchors shall be at least 2 ft. long and the maximum spacing shall be 4 ft.

"Meeting or intersecting non-bearing walls shall be bonded or anchored to each other in an approved manner."

(d) Chases and Recesses. "There shall be no chases in walls of less than 12-in. nominal thickness or within the required area of any pier, and no chase in any wall shall be deeper than one-third the wall thickness, except that in dwellings not over two stories in height vertical chases may be built in 8-in. walls under the following limitations:

"In 8-in. bearing walls the chases shall not exceed 4 in. in depth, 30 in. in width, and 2 ft. in height and shall not extend below the level of joist bearing, provided that where such chases occur below window sills the width may be not in excess of the width of the window opening above. In any case, not less than 4 in. of masonry shall remain between the back of chase and exterior surface of wall, and the backs and sides of all such chases in exterior walls shall be waterproofed and insulated. Masonry directly over chases wider than 12 in. shall be supported on lintels. Chases permitted in 8-in. walls shall not be cut but shall be built in as construction progresses.

"No horizontal chase shall exceed 4 ft. in length, nor shall the horizontal projection of any diagonal chase exceed 4 ft. in length. There shall be at least 7¾ in. of masonry between chases and the jambs of openings.

"Recesses for stairways or elevators may be left in walls, but in no case shall the walls at such points be reduced to less than 12 in. unless reinforced by additional piers, or by columns or girders of steel, reinforced masonry, or concrete, securely anchored to the walls on each side of such recesses. Recesses for alcoves and similar purposes shall have not less than 8 in. of material at the back. Such recesses shall be not more than 8 ft. in width, and shall be arched over or spanned with lintels.

"The aggregate area of recesses and chases in any wall shall not exceed one-quarter the whole area of the face of the wall in any story.

"Chases and recesses shall not be cut in hollow walls, cavity walls, or walls of hollow masonry units, but when permitted may be built in."

(e) Separation of Combustible Structural Members. "No wall of 8-in. nominal thickness shall be broken into, subsequent to building, for the insertion of structural members.

"A separation of at least 4 in. of solid masonry shall be provided between combustible members which may enter walls from opposite sides.

"When unprotected, steel or combustible structural members frame into hollow walls of thickness not greater than 12 in., they shall project not more than 4 in. into the wall and shall be so spaced that the distance between embedded ends is not less than 4 in. The space above, below, and between such members shall be filled solidly with burned clay materials, mortar, concrete, or equivalent fire-resistive material to a depth of not less than 4 in. on all sides of the members.

"All open cells in tile or blocks occurring at wall ends shall be filled solidly with concrete for a depth of at least 6 in., or closure tiles set in the opposite direction shall be used."

713. RESISTANCE TO WEATHERING

The resistance of masonry walls to weathering is primarily dependent upon their resistance to rain penetration since freezing and thawing in the presence of moisture is practically the only action of weathering which affects clay products masonry.

As in the case of structural design, the design of walls to resist rain penetration should be based upon the exposures to which they will be subjected. These exposures vary greatly in different parts of the United States; the more severe being associated with areas of high precipitation (over 30 to 40 in. of rainfall per year) accompanied by winds of high (50 mph. and over) velocity.

Variations in the severity of exposures to rain penetration undoubtedly account for the differences of opinion which exist as to the performance of various types of wall construction. It is frequently reported that a wall leaks which is built of the same materials and similar workmanship as that used in the construction of a wall that has satisfactorily resisted rain penetration. Often it is assumed that the second wall differs materially from the first, while, in many instances, the difference in the performance of the two walls is due to the different conditions to which they are exposed.

Extensive laboratory tests indicate that with controlled workmanship it is possible to construct brick and tile walls which are watertight and will resist penetration of rains of 12 to 24 hr. duration when accompanied by winds of 50 to 60 mph. velocity. However, experience and the records of

performance of buildings subjected to severe storms indicate that the workmanship customarily obtained in commercial construction will not resist such exposure and, for this reason, it is recommended that in areas subject to severe exposure, as previously defined, walls be designed on the assumption that some moisture will penetrate the exterior surface and that positive means be provided to conduct this water to a drain or to the outside of the wall before it reaches the interior face.

Cavity walls and various structural tile walls, in which the units contain drainage channels, incorporate this feature in their design and are recommended for such locations.

The resistance of brick and tile walls to rain penetration depends both upon the design and the workmanship employed in the construction. The design, perhaps, is of primary importance because even the best workmanship cannot assure satisfactory performance of a poor design.

Important features of design insofar as they affect rain penetration are adequate flashing, tooled mortar joints, tightly caulked door and window frames, sufficient wash or slope to readily drain all horizontal projecting surfaces, such as sills and copings, including an overhang and drip, and adequate gutters and downspouts.

The properties of masonry materials (units and mortars) and the types of workmanship which contribute to watertight masonry were the subject of an investigation at the National Bureau of Standards which extended over a period of approximately 8 years. A summary of the results of this research is given in Section 610, Chapter 6.

Following the Bureau's investigation, D. E. Parsons, formerly Chief of the Masonry Section, and now (1950) Chief of the Building Technology Division of the National Bureau of Standards, presented recommendations affecting materials and workmanship which contribute to watertight and strong masonry walls in an address, "Watertightness and Transverse Strength of Masonry Walls", before the 1939 Annual Meeting of the Structural Clay Products Institute. The following, quoted from Mr. Parsons' address, is a summary of his recommendations:

"*1. Method of Constructing Watertight and Strong Joints.* A desirable method for laying joints in masonry is one which provides a barrier against the entrance of water and a complete bonding of the mortar with the masonry units at a minimum cost. The moisture barrier may be provided by means of solidly filled joints throughout the wall, but especially in the facing, or it may consist of a plaster coating of mortar applied to the face of the backing or to the back of the facing. Although there appears to be no simple alternative, a choice of methods for obtaining well filled joints is possible. Mortar may be applied to the ends of stretcher brick and the sides of header brick before they are laid, thus filling vertical joints at the time these brick are placed. Filling may be accomplished by the pick and dip method, in which mortar is thrown on the bed joint immediately prior to the laying of each brick. The brick is then shoved into position which tends to fill both the horizontal and the vertical joints. Or the vertical joints may be filled by slushing or by grouting after the brick have been placed. The last methods may not be as effective as the others unless the suction rate of the brick and the workability of the mortar or consistency of the grout are within the optimum ranges. Although the leakage resistances of walls with furrowed bed joints were not appreciably inferior to those with solidly filled bed joints (however obtained), the transverse strengths were less.

"*2. Controlling Suction Rate of Brick.* The most desirable suction rates for brick were from 0.2 to 0.7 avdp. oz. per min., both for walls of high resistances to rain penetration and to transverse loads and also for complete and strong bonding of the mortar to the units. Walls which did not leak were constructed of brick having suction rates less than 0.2 oz. However, there was a tendency for these brick to 'float' and for the walls to become distorted by the brick moving out of position, thus delaying construction. Usually floating was not troublesome when there was no surface water on the brick. An exact control of the suction rate was not necessary. The masons easily judged when the brick were too wet. Perhaps the most satisfactory method for wetting highly absorptive brick is to spray them in a pile until water flows from all portions, several hours prior to their use. As the more absorptive units tend to absorb water more rapidly than those of lower absorption, the spraying may tend to produce uniformity in the suction rate."

(Suction rate as used by Mr. Parsons is the weight of water absorbed by the brick surface which will be in contact with mortar when 30 sq. in. are emersed in water to a depth of ⅛ in. for 1 min. See Section 610, paragraph (b).)

"*3. Controlling Mortar Properties.* The results of investigations indicate that it is possible to construct walls having a high resistance to rain penetration with mortars of poor working qualities. However, it is much easier when the workability of the mortar is such that a minimum effort is demanded from the mason. Although masons have their own technique in judging the working qualities of mortars, others may gain a rough estimate by observing their performance in two respects: first, a mortar of poor workability stiffens rapidly when on an absorptive unit; and secondly, it tends to 'bleed', that is, to segregate with a separation of the water when standing on an impervious base. Good workability and high strength are not incompatible, and, by an appropriate choice of materials, it is not difficult to prepare mortars of excellent working properties which will develop high strengths. (General requirements for and properties of mortars and mortar materials are discussed in Chapter 5.)

"*Conclusion.* The protection against rain and lateral forces afforded by the wall of a building may depend upon the inherent resistance of the walls. For example, suitable flashings over openings, which are always desirable, are necessary for assurance against leakage with walls having water permeable facings. Resistance of walls to horizontal forces depends largely upon the strength and spacing of the lateral supports. For a particular design, however, the watertightness and transverse strength of masonry walls are governed largely by qualities of the joints.

"The conditions favoring the construction of strong and leakproof joints in masonry may be stated more completely and precisely in values measurable by means of laboratory instruments and methods than in general terms. However, their statement in general terms may be helpful in directing attention to the important factors and in providing a rough guide to builders.

"The resistance of masonry walls to rain penetration was governed more by the method of laying the joints than by any other factor. Most walls with solidly-filled vertical joints (however obtained) or with a continuous parging of mortar in the interior were highly resistant. The likelihood of obtaining a complete and strong bond of mortar to brick and tight joints was greatest when the brick were as wet as they could be without excessive floating and the

joints were completely filled with a water retentive mortar containing the maximum amount of water compatible with satisfaction of the mason."

714. FLASHING

(a) Purpose. At the outset, it might be stated that no flashing at all is better than poor flashing. Improper materials may be destroyed by corrosion or damaged by movement of the structure, and even good materials may be improperly installed. The result is that instead of excluding or controlling moisture, defective flashings tend to collect it in a manner to cause serious damage to the structure.

Unless the complete protection of the structure against moisture penetration justifies an expenditure sufficient to guarantee adequate and effective flashing, it is good economy to omit the flashing altogether and to rely on maintenance (frequent repointing of mortar joints in horizontal surfaces and other vulnerable spots) to prevent the entrance of water into the wall. To merely specify flashing and then trust to chance that it will be effective has proved most disappointing in many installations.

External or applied flashings are those which prevent the absorption by vertical masonry construction of water accumulating on relatively flat intersecting surfaces. Such flashings usually consist of two members, the base flashing which forms a part of the covering of a flat surface and turns up against an intersecting vertical surface, and the cap or counter flashing which is built into the vertical surface and turned down over the base flashing. Internal or through flashings are those built into and usually concealed within the masonry to control the travel of moisture and direct it to the exterior surface. It is desirable that some external flashings become also through flashings, particularly in the case of counter flashings. In general, the ends of through flashings should be turned up to prevent drainage into the wall; the back should be turned up if below the roof line and turned down if above the roof line; and wherever possible, the front of the flashing should extend through the wall and be turned down to form a drip. All flashing should be drained to the outside. Tests at the National Bureau of Standards of concealed flashings in tooled mortar joints indicate that such flashings are not self-draining but serve as a trap to collect the moisture. Flashing should be drained either by "weep holes" spaced 2 ft. on center in the mortar joint in which the flashing is placed or by wicks consisting of ¼-in. cotton rope or similar material spaced 18 in. on center.

(b) Where Flashing Is Required. The vulnerable points of a masonry structure where flashing is necessary or recommended for good construction will be described in the order of their occurrence in the progress of construction. They are at the grade line, the sills and heads of openings, spandrel beams, the intersection of vertical and horizontal surfaces, and at parapet walls.

(c) Flashing Materials. Flashings are usually formed of sheet metal or bituminous membrane materials, the selection being greatly influenced by cost. The cost of installation is practically the same for any material, so the cost variation lies mainly in the material itself. The cost of replacing defective flashings will probably greatly exceed the original saving on material, therefore it is advisable to select a permanent material for the original installation.

Tin and galvanized iron may be used for flashings, but they are subject to corrosion and require maintenance. Other metals suitable for flashings are copper, lead, zinc and aluminum. Of these, copper is generally preferred for good work as it does not deteriorate when exposed to weather or to masonry materials. The principal objection to copper is that, where exposed to weather, it may stain or discolor light colored masonry surfaces. This may be prevented, however, by the use of lead coated copper at such places. While lead is attacked by cement mortar and fresh lime mortar, this action is negligible near the masonry surface because the mortar carbonates quickly and the lead coating remains effective. Copper sheets are available for through flashing, formed with corrugations and indentations to provide mechanical bond with the masonry and interlocking joints where the sheets lap.

Bituminous membrane materials are composed of asphalt or tar saturated fabrics and they are usually laid in and covered with a bituminous waterproofing compound applied with a trowel or brush. If these materials are not permanently insoluble in water they also may produce stains or discoloration on the masonry and should not be used where this would be objectionable.

(d) Damp Check. Moisture from the ground may be absorbed by exterior foundations and travel upward by capillary action into the wall above. This should be prevented by the installation of a damp check consisting of a continuous through flashing covering the full thickness of the wall and having tight end joints. It should be placed about 6 in. above the finished grade, platforms, or other exposed surfaces as further protection against moisture from rain splash or snow. This flashing, if of metal, may be increased in width to project over one or both faces of the wall to form a termite shield. Slate has been frequently used for this purpose and is satisfactory as a moisture barrier if the edges are well lapped. It must be bedded in mortar and, with the lapped joints, increases the thickness of the mortar bed to an extent that it may mar the appearance of the wall. In case of uneven settlement it may also be broken, in which case dampness may penetrate the upper wall.

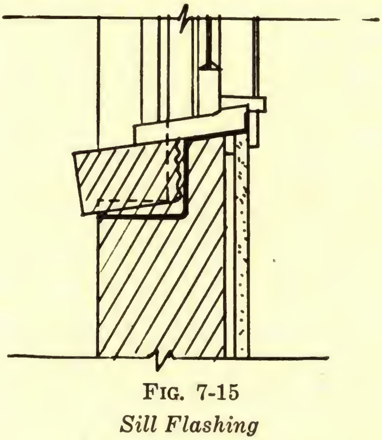


FIG. 7-15
Sill Flashing

(e) Sills. Unless made of an impervious material in one piece, all sills should be provided with through flashing. This flashing should be formed to fit under and behind both the masonry and the wood sills. The ends should

extend beyond the jamb lines and be turned up at least 1 in. into the wall to keep any accumulated moisture from entering the wall at these points. If the sills are of cast stone, the ends should be full height, forming closed end pans.

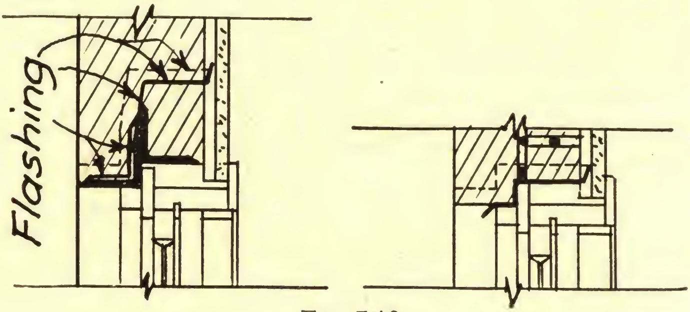


FIG. 7-16

Steel Lintel *R-B-M Lintel*

(f) **Heads.** The heads or lintels of openings should be treated similarly to sills with through flashing. For steel lintels, the flashing is placed under and behind the facing wythe of masonry and over the top of the lintel. Bend the front (exterior) edge of the flashing down over the edge of the angle to form a drip and thus eliminate moisture entering and causing the angle to rust. A bituminous coating on top of the outer edge of the angle may help seal this space. For reinforced masonry lintels that are not grout-filled, the flashing is placed between the masonry and the frame, the front edge turned down as a drip over the face of the frame. In all cases the ends should be formed as for sills and the back turned up 1 in. against the inner face of the wall or of the furring. (RBM and other masonry that is grout-filled requires only a damp-check).

In cavity walls, the same methods are followed, the flashing sheet extending across the cavity and into the inner wythe one or two courses higher than at the outer wythe.

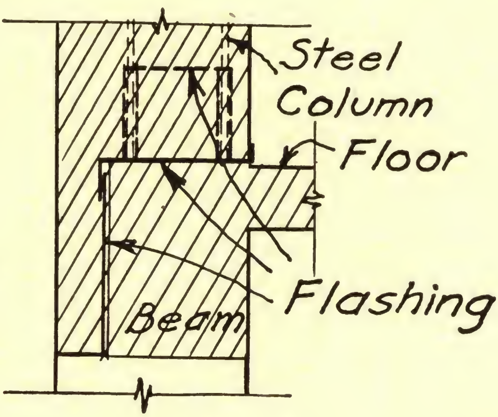


FIG. 7-17

Spandrel

(g) Spandrels. In skeleton framed structures, the spandrels should be flashed continuously at the beams. The flashing should start under the facing wythe at its supporting member, extend upward behind the facing wythe and over the top of the beam, which is usually the rough floor level, and turn up at the inside face of the masonry wall or furring. This portion may be formed in two or more overlapping sections to simplify installation. It should also turn up about 6 in. high around columns above the beam, allowing ¼ in. clearance between column and flashing metal, with tight bottom joints, and the top sealed with mastic.

Copper is the most satisfactory material for this purpose, but it is necessary that the sheets be carefully fitted, especially at columns, and all joints soldered tight.

(h) Projections. All projections and recesses from the exposed face of a wall tend to retain rain water and snow and should, therefore, be designed with a slope or wash on top to drain off the water and, if possible, a drip to throw the water clear of the wall surface below. They should also be flashed, preferably over the top, with the outer edge of metal bent down and folded as a

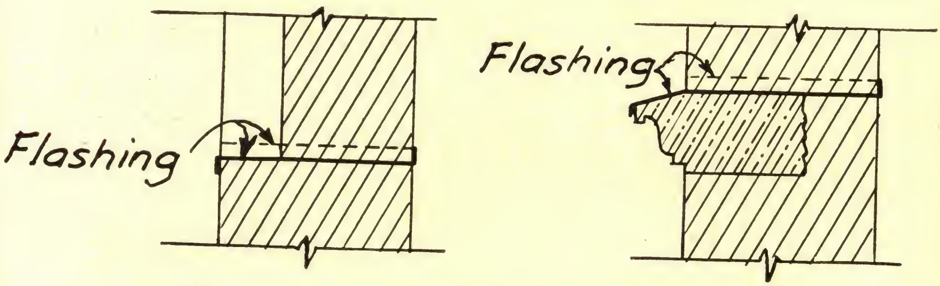


FIG. 7-18

Recess *Projection*

drip and the back extending through the wall and turned up against the inner face of the wall if below the roof flashing. If made of cast stone, all courses, either projecting or flush, should have through flashing in the mortar bed below the cast stone, or this flashing may be formed as closed end pans as described for cast stone sills.

(i) Roofs. The design of base flashing depends upon the kind of roofing material used. Where the base flashing is of metal, the counter flashing should also be of metal extending through the wall and turned down overlapping the base flashing. At chimneys, it should extend through the chimney walls and turn up at least 1 in. against the flue lining.

The most satisfactory method of flashing built-up roofing is by extending it into raggle blocks built into the wall, and through flashing should be placed in the mortar bed on top of the raggle block. Without raggle blocks, the roofing material may form the base flashing, in which case the through flashing, extended and bent down, also becomes the counter flashing. See Fig. 7-19.

(j) Parapets. Parapet walls should be built of good materials and backed with the same quality material as on the exposed side. This applies as well to other roof structures so frequently neglected because they are not exposed

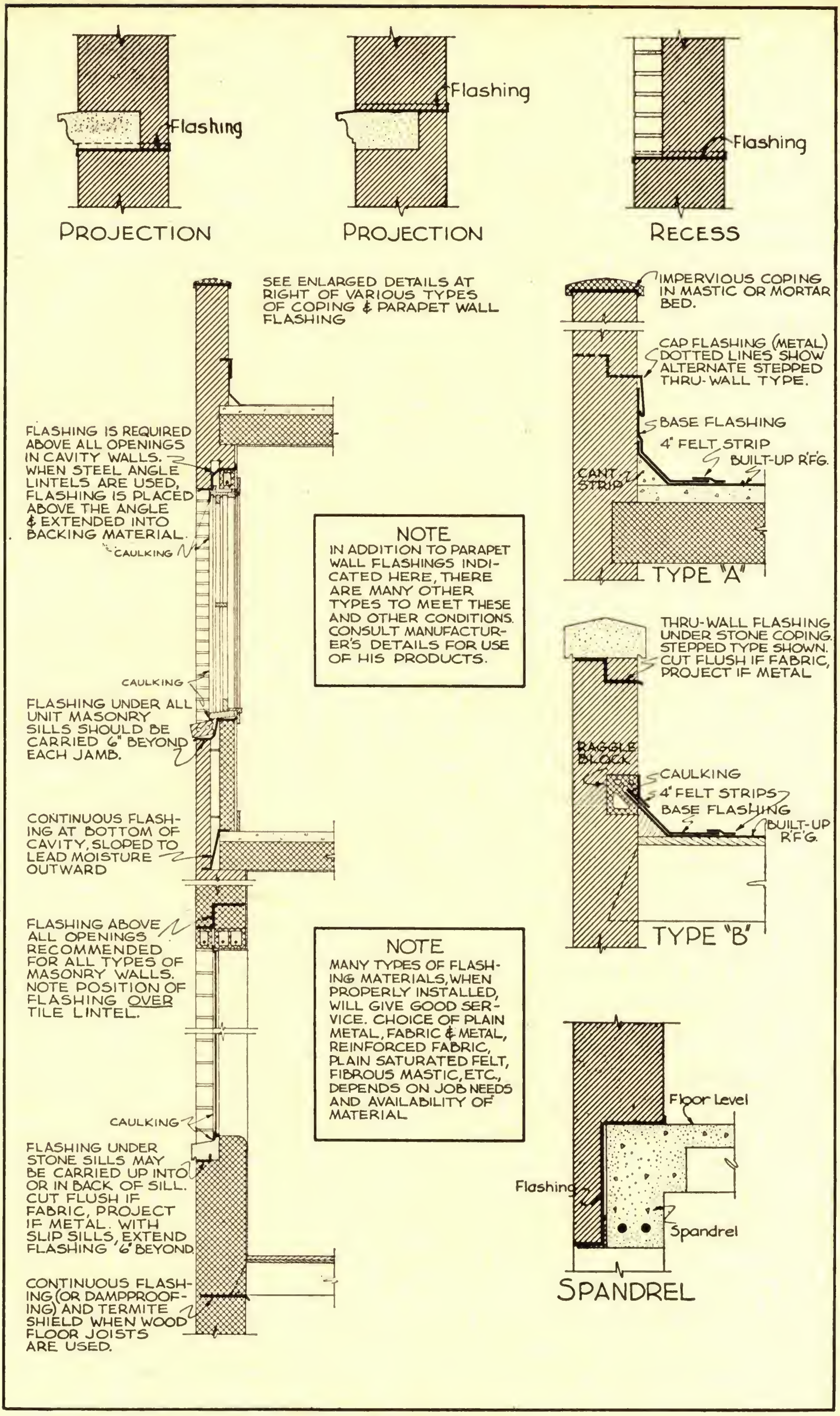


Fig. 7-19

Flashing details for structural clay masonry walls.

to view. *The backs of parapets should not be painted or coated in any manner, but instead left free to dry rapidly.* If they must be covered, the material used should be erected free from the wall in a manner to permit circulation of air between the covering and the masonry.

In all cases, through flashing should be placed in the mortar bed under the coping unless it is of an impervious material with watertight joints. Where the coping provides suitable drip the flashing may stop at the wall surface, otherwise it should be turned down ¼ in. to form a drip on both sides.

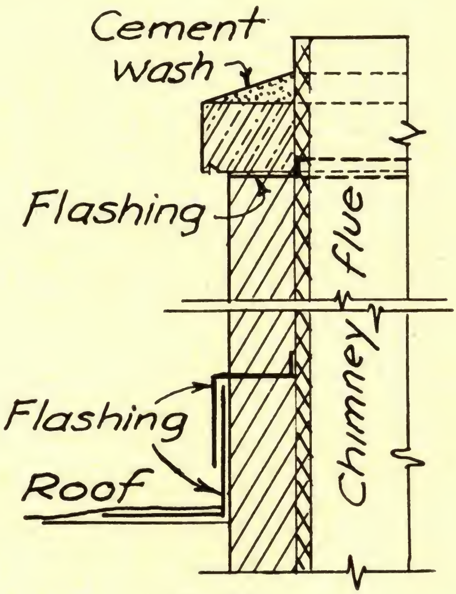


FIG. 7-20

Chimney Flashing

(k) Chimney Tops. Through flashing, as described for parapets, should be placed under chimney tops, cut out for flues and turned up tight against the flue linings.

715. PREVENTION OF STAIN

The appearance of many otherwise well designed buildings is often materially marred by unsightly stains on the masonry, caused by the deposit of such material as iron rust or dirt. By far the most prevalent cause of this staining is the wash of excessive amounts of dirty water over relatively small wall areas. Such staining may be observed below sills and band courses which have inadequate projections and have not been designed with a drip. This concentration of water on the wall surface, in addition to depositing dirt washed from windows and wall areas above, will in most cases cause efflorescence resulting from the excessive saturation of the masonry. Ferrous metal brackets or railings attached to masonry walls also frequently cause unsightly stains which are practically impossible to remove by any means other than sand blasting.

Details which will prevent staining are so simple as to appear obvious and from the prevalence of its occurrence it would appear that many designers do not include such details in their working drawings but rely upon the contractor or building mechanics to take such steps as may be necessary to prevent staining.

Unless provision is made to dispose of the water which accumulates on sills through downspouts built into the exterior wall, as is done in some types of modern architecture where projecting sills do not conform to the architectural pattern, sills and band courses should project from the face of the wall at least 1 in. and should be provided with a V slot on the under side to create a positive drip to keep the water from running back under the sill and down the face of the wall.

The top surface of sills with a flat slope (⅛ in. per ft. or less) should be so shaped to divert the water toward the center of the opening and away from the corners.

Ferrous metal attached to masonry walls should be separated from the walls by a gasket of non-corrodible, durable material so shaped to form a drip to divert the wash from the fixture away from the wall.

Fig. 7-21 shows typical construction details to prevent staining.

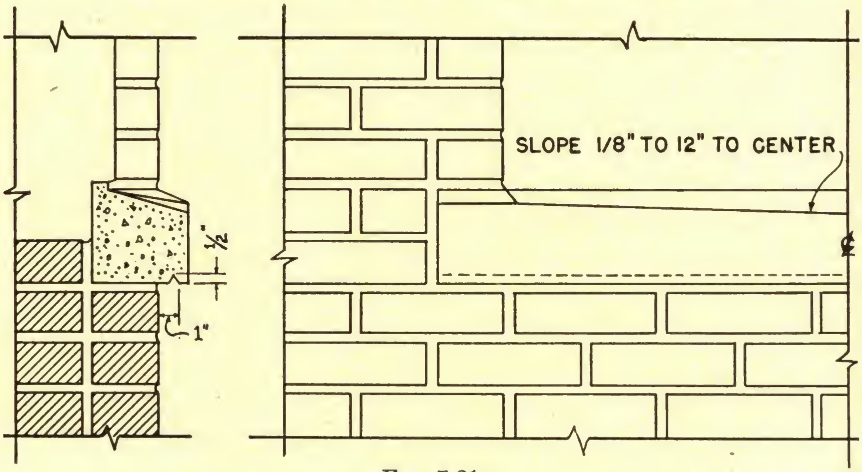


FIG. 7-21
Typical construction details to prevent staining.

716. DAMPPROOFING AND WATERPROOFING

In general, dampproofing or waterproofing should not be necessary for masonry walls above grade; it is recommended for foundation walls, retaining walls and similar structures. Certain types of waterproofers have been found to reduce the leakage of walls above grade; however, the claims made by many producers are not substantiated by laboratory tests nor actual performance.

The following, quoted from the 1940 Report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete, is equally applicable to unit masonry walls and, as regards integral waterproofing, masonry mortars:

"*Dampproofing* (a) Water which enters the concrete wall by absorption will be distributed by the capillary forces throughout the concrete until a condition of saturation is reached or until evaporation balances the inflow. If there is a continuing supply of free water available on one surface and evaporation can take place from another, there will be a continuing passage of water. If the air becomes saturated or the temperature drops sufficiently, moisture will condense on the wall. When this occurs, or if a seal coat is applied to the face away from the source of the moisture, the outflow of water ceases and saturation of the concrete is encouraged. The prevention of moisture penetration by capillarity is commonly referred to as 'dampproofing' as contrasted with 'waterproofing', which implies the prevention of an actual flow of water through the structure.

"(b) The appearance of moisture on a wall does not always indicate, of course, that the water vapor in the air is entirely due to passage of water through the wall. Oftentimes, dampness on the inside of a wall is mistakenly ascribed to moisture penetration, when in fact it is merely the result of condensation, on the cold wall, of moisture which originated elsewhere.

"(c) Dampness due to absorbed water or condensed water vapor can develop on and within concretes through which water will not "flow" even under great pressure. The remedy is to seal the pores on the side exposed to the moisture. Most of the methods mentioned below for waterproofing should be effective in preventing the entry of water into concrete. Other and more simple methods might also be effective. The use of a seal coat on the side away from the water may be effective for some time, but if the wall is subject to freezing temperatures the use of such seal coat may in the long run result in greater damage than leaving the wall unprotected.

"*Coatings on the side away from the water pressures.* The desirable procedure in waterproofing a structure is to apply protection on the side exposed to water pressure. Frequently, however, this is impossible and it is necessary to apply waterproofing on the opposite side. Where the waterproofed surface is protected from freezing temperatures, this procedure has some advantage in that, in the case of failure of the waterproofing, it is easier to locate the source of weakness and make the necessary repair. Where the waterproofed surface is to be exposed to freezing temperatures, however, the method is not recommended. The freezing of water in the concrete immediately underneath the protective coating will not only damage the coating, but injure the concrete itself. The concrete may be affected more rapidly with the coating than it would if the coating were absent, when there would be less opportunity for the concrete to become saturated at the surface.

"*Waterproofing with Portland Cement Mortar.* (a) A plaster coat of portland cement mortar on the side of a wall exposed to water pressure, when properly applied and cured, will effectively protect porous concrete against the penetration of water under pressure. However, any structural movement resulting from load, settlement, shrinkage, etc., which will crack the structure, will crack the plaster, thereby destroying its waterproofing value at these points. The use of this type of waterproofing, of course, would require that any cracks existing in the concrete be chipped out and filled with mortar before applying the plaster coat.

"(b) Portland cement plaster applied on the side of the structure away from the water pressure has been successfully used against considerable heads. Cracks and defective spots are readily fixed by mortar applied from the

inside. When skillfully done, this method can be used to shut off actual flowing leaks. When the quantity of water flow is considerable, some accelerating agent, which will reduce the setting time to a few minutes, may be necessary.

"(c) This method of waterproofing has the advantage that cracks occurring after the plaster is in place can be readily located and repaired. It does not, of course, prevent possible damage to the structure from corrosion or weathering even though the interior may be kept dry. It should not be used where the surface is to be exposed to freezing temperatures. The method, however, has its uses and in some instances may be the only possible one.

"(d) Good plastering technique is required for successful waterproofing with portland cement plaster, whether applied on the inside or the outside. This includes such details as clean surfaces, proper suction at the time of application, plastic consistency, and the proper curing of each coat. The mortar should be about a 1:2 mix applied in at least two coats, each coat about ⅜ in. thick. Powdered iron preparations are sometimes added to the mortar.

"*Integral Waterproofing.* (a) Powdered Admixtures. Misconception of the function of admixtures and frequent overstatement of their properties have led to much misunderstanding regarding their use. In very lean mixtures almost any fine, inert material will improve the watertightness of concrete. This improvement comes about in two ways. First, with the extra fines the paste will have a more plastic consistency which will segregate less and be more watertight. Second, the more plastic paste will improve the workability of the concrete and thereby guard against those defects in placing which leave open channels for water to pass through the member.

In rich mixes, on the other hand, where the cement-water paste is already of plastic consistency, and of sufficient quantity to give the needed workability, powdered admixtures serve no useful purpose so far as watertightness is concerned. For mixtures in this range most of the powdered admixtures require increased water content, as compared with the plain mix, which reduces the quality of the paste and detracts from its watertightness.

"The field of powdered admixtures, therefore, for waterproofing concrete will depend upon the character of the concrete mix just as much as upon the characteristics of the admixtures. Lean mixtures or normal mixtures deficient in fines in the aggregate can be improved by some of the admixtures. On the other hand, rich mixes, and normal mixes in which adequate fines are present, may be reduced in watertightness by the presence of these added fines.

"(b) Water-Repellent Admixtures. Stearates or other water-repellent materials have found considerable use as admixtures for concrete where the penetration of moisture is to be retarded. These materials reduce the absorption and retard penetration of moisture by capillary action. They do not seem to be effective as waterproofing when the concrete is exposed to direct water pressure. Some of these water-repellent admixtures improve the workability of concrete and thereby may improve the watertightness of a wall exposed to direct water pressure.

"*Waterproofing with Surface Treatments.* (a) There are a number of surface materials which can be applied to concrete for protection of the surface against weathering or other attack. * * * In the following paragraphs are listed some of those which have been found particularly adaptable.

"As in the case of cement mortar plaster, any structural movement

which creates a crack will break these applied coatings and destroy their waterproofing value at these points. Likewise, none of these surface treatments is of sufficient body or strength to span cracks already in the structure and prevent the entrance of water. As pointed out, these materials, when used on the side away from the pressure, may accelerate deterioration of a wall if exposed to freezing temperature.

"(b) Bituminous Coatings. There are a number of asphaltic and tar coatings which are available for application to concrete. Some of these are to be applied hot; others, which depend for their hardening on the evaporation of a liquefier, are to be applied cold. The extent to which these materials can waterproof concrete and the period over which the protection will remain effective, depend not only upon the materials themselves, but on the condition of the concrete to which they are applied and the type of exposure to which the surfaces will be subjected. This same comment might with equal propriety be applied to the other materials mentioned below.

"(c) Oil, Oil Paints, or Oil Resin Combinations. Linseed oil by itself, or in combination with resinous varnishes, makes a very satisfactory coating material for ordinary weathering and many other types of exposure. Oil paints based on linseed or other weather-resisting oil also have value. The preparation of the surface and the application of the materials should be done in accordance with the best painting technique with particular reference to the type of materials being used.

"(d) Portland Cement Paints. Mixtures of portland cement and water or specially prepared combinations consisting mainly of portland cement are shown to have considerable value in resisting the penetration of water into concrete surfaces under conditions of moderate exposure. The use of these materials requires that special attention be given to curing methods to develop their greatest effectiveness.

"(e) Powdered Iron Preparations. Mixtures of pulverized iron and cement, usually with some agent designed to hasten the oxidation of the iron, have been used for waterproofing concrete surfaces. These are usually applied with a brush, either in a thin coating like a paint, or in a stiffer consistency to a measurable thickness. The waterproofing effect is considered to result from the formation of the oxide of iron within the pores of the concrete. The agent most commonly used to accelerate the oxidation of the iron is ammonium chloride. These materials are also sometimes mixed with cement mortar for use in waterproofing.

"(f) Proprietary Surface Treatments. Many surface treatments of a proprietary nature are available for painting concrete which are based on some of the foregoing or similar materials. The use of such proprietary compounds should be restricted to those which have been proven by service test and which are susceptible to tests that will insure uniformity. They should always be limited to the type of service for which they are intended and the method of application should be strictly in accordance with the directions of the manufacturer.

"*Bituminous Membrane Waterproofing.* (a) This method is particularly adaptable to large areas where there is some uncertainty as to the possibility of further cracking in the structure which would render other forms of waterproofing ineffective. It involves the use of a membrane consisting of one or more layers of bitumen saturated cotton fabric or felt, or combinations of both materials cemented together (and to the surface waterproofed if a priming coat is used) by means of bituminous coatings. The bitumen to be used for

the saturant and coating should be either asphalt or tar. The technique of applying this type of waterproofing is well established and organizations and workmen experienced in its use are generally available.

"(b) Where there is any possibility that the membrane will be punctured by the backfilling material, it should be protected by an additional layer of masonry or by some such method as portland cement mortar or bituminous mastic, or by an asphalt blanket or bituminous mastic blocks."

717. REPAIR OF LEAKY WALLS

Leaks through masonry walls may be the result of defective flashing, incomplete caulking around window or door frames, or defective wall copings. If so, the remedies are obvious and relatively easy to apply. However, if the leaks occur through openings in the mortar joints, due primarily to incomplete filling of these joints, any remedy is difficult and expensive.

The most effective means of stopping moisture penetration through openings in mortar joints is to cut out the mortar to a depth of ½ to ¾ in. and repoint with a plastic mortar meeting the requirements of the mortar specifications in Chapter 5 for prehydrated, Type B mortar. Repointing is effective when applied to brick faced masonry walls or structural tile walls in which the mortar joints are at least 1 in. in depth.

A less expensive method of waterproofing leaky walls consists of scrubbing a cement grout into the mortar joints. This treatment was applied to a large housing project in 1940 and has been effective since that time in eliminating excessive wall leakage. In applying the grout to the mortar joint, a template is used to protect the masonry from discoloration and the grout is brushed into the mortar joint with a stiff fiber brush.

The grout mixture recommended consists of 1 part cement, 0.25 part hydrated lime and 2 parts sand passing a No. 30 sieve, by volume.

Building Materials and Structures Report BMS95, "Tests of Cement-Water Paints and Other Waterproofings for Unit-Masonry Walls," by Cyrus C. Fishburn and Douglas E. Parsons, issued under date of March 15, 1943, is a report of extensive tests on various methods of waterproofing brick and tile walls.

Tests of these walls were conducted immediately after the waterproofing treatments were applied and after periods of one to two years of outdoor exposure. These latter tests indicate the durability of various types of waterproofing compounds. The waterproofing of masonry walls is a subject on which there appears to be much misinformation. BMS95 is a valuable guide to architects and builders in specifying methods of waterproofing.

The following summary of the report is reproduced from the Technical Notes Bulletin of the National Bureau of Standards, May 1943:

Building walls in exposed locations are sometimes penetrated by wind-driven rain with subsequent damage to plaster and interior trim. The effectiveness of cement-water paints and of other waterproofings for unit-masonry walls was studied by Cyrus C. Fishburn and Douglas E. Parsons, who measured the water-permeability before and after treatment of small wall specimens that leaked when exposed to simulated service conditions. The durability of some of the treatments was measured by again testing the walls after they had been stored outdoors for 1 or 2 years.

Cement-water paints were found to be highly resistant to water penetration and were more effective than emulsified resin or oil base paints. The

cement-water paint coatings were durable and proved effective as waterproofings after 1 or 2 years of exposure, although some of the specimens were so weather-stained that their repainting might have been considered desirable from the standpoint of appearance. On rough-textured concrete block walls, the cement-water paint coatings were most effective when applied with stiff, fender-cleaning brushes rather than with soft-bristled whitewash or paint brushes. The admixture of fine sand in the first coat of paint applied to walls of rough-textured units, such as cinder-concrete block, was highly effective. Such coatings were durable and contained few or no pin holes. Coatings made of cement-water paint of thin consistency were more permeable than those made from a paint of medium consistency, but heavy applications of a medium consistency paint were less durable than thinner coatings of the same paint. Cement-water paint coatings applied to dry walls were more permeable than similar coatings applied to backings that had been wetted and were damp when painted.

Colorless waterproofing materials were of little or no benefit as waterproofing when applied to walls that leaked badly. Of the colorless materials tested, only one was effective, and walls treated with it were highly permeable when again tested after they had been exposed outdoors. The only effective and durable waterproofing treatment for brick walls that did not change the appearance of the wall was repointing or grouting of the face joints.

Bituminous coatings applied to the inside, unexposed, faces of the specimens were ineffective as waterproofing and were badly blistered after a test exposure lasting 1 day. Brush coatings of portland cement and sand were more effective than bituminous coatings, but were not as effective as trowel coatings of cement and sand prepared with or without admixtures of powdered iron and salammoniac (iron waterproofing).

718. FIRE PROTECTION

Until comparatively recently, fire resistive requirements of building codes were established more or less arbitrarily as a result of experience gained from fires. However, the authors of National Bureau of Standards Report BMS92, which was published in October 1942, suggest a more rational approach to the problem, which is that fire resistive requirements be based upon the total combustible content of the occupancy for which the building is designed.

Burn-out tests conducted at the National Bureau of Standards, which were performed in fireproof structures with various concentrations of combustibles having calorific values in the range of wood and paper (7000 to 8000 Btu per lb.) and assembled to represent building occupancies, indicate that the relation between the amount of combustibles and the fire severity is approximately as given in Table 7-7 which is reproduced from Report BMS92.

"Fire Protection Through Modern Buiding Codes", by B. L. Wood, published by the American Iron and Steel Institute, is a comprehensive treatise on fire protection and building code regulations affecting fire safety. In addition to analyzing the data presented in BMS92 and recommending building code requirements for fire resistance, Mr. Wood suggests a rational basis for establishing limitations on height and area of buildings. This publication is recommended as a valuable reference for those interested in fire protection.

The principle of basing structural requirements upon occupancy is

utilized in determining the required strength of floors and other structural members and, where the future occupancies of the building can be predicted, it would seem to be a more rational method of establishing fire resistive requirements than former practice.

Fire endurance ratings of brick and tile walls, based on extensive fire tests, are given in Tables 6-25 to 6-31, inclusive, of Section 608, Chapter 6.

TABLE 7-7

RELATION OF AMOUNT OF COMBUSTIBLES TO FIRE SEVERITY

Average weight of combustibles, psf. of floor area	Fire severity hr.	Average weight of combustibles, psf. of floor area	Fire severity hr.
5	½	30	3
7½	¾	40	4½
10	1	50	6
15	1½	60	7½
20	2		

719. SOUND REDUCTION

The authors of National Bureau of Standards Report, BMS17, make the following statement regarding factors which control the transmission of sound through walls and floors.

"Noise may enter a building by the following means:

"1. By transmission of air-borne sounds through openings, such as open windows or doors, cracks around doors, windows, water pipes, conduits, or the ducts of ventilating systems, etc.

"2. By transmission of structural vibrations from one portion of the building to another.

"3. By direct transmission through the various portions of the building structure, which act as diaphragms set in motion by the sound waves striking them.

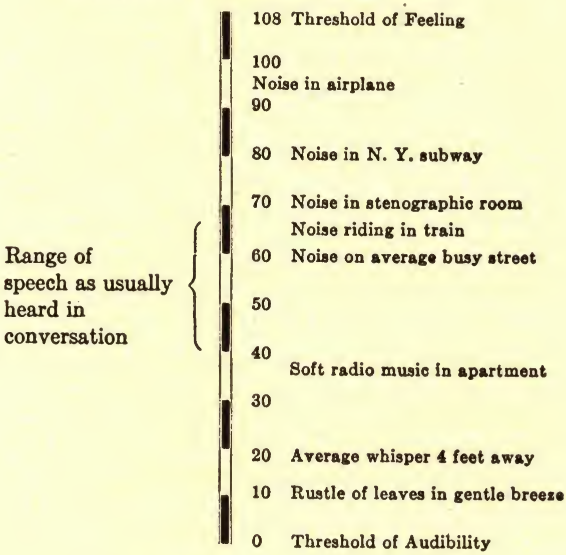
"The method of preventing the transmission of sound by the first means is quite evident, but it is not always easy to control these conditions. However, cracks can be reduced to a minimum and where a high degree of sound insulation is desired windows should be eliminated wherever possible. Ventilating ducts present a serious problem, but by inserting a properly designed acoustic filter in the duct, most of the noise can be eliminated.

"Prevention of sound transmission by the second means is a structural detail which should be taken into consideration when the building is designed. Some materials do not transmit vibration as readily as others and this difference in the materials can sometimes be used to advantage. One of the most common methods is the use of a nonhomogeneous structure, or when possible, the complete separation of the two parts of the structure.

"The prevention of sound transmission by the third means is a problem which it has been possible to study in the laboratory to better advantage than when sound is transmitted by the other methods. By sound insulation of a wall, partition, or floor is meant the insulation with respect to the transmission of sound by this means. In an attempt to understand this diaphragm action, let us consider some of the factors which control the transmission of

sound through a panel. Let us consider how sound passes through a sheet of window glass. The sound energy is transmitted to one side of the glass by air. The impact of the successive sound waves upon the glass causes it to be set in motion like a diaphragm, and because of this motion, energy is transmitted to the air on the opposite side. The amount of energy transmitted through the glass depends upon the amplitude of vibration of the

SENSATION UNITS (DECIBELS)



EAR SENSATION SCALE

FIG. 7-22

Decibel scale of sound intensities.

glass. This in turn depends primarily upon four things—the initial energy striking the glass, the mass of the glass, the stiffness of the glass, and the method by which the edges of the glass are held, especially as it affects the damping of the motions of the glass. There is a fifth factor which is occasionally of importance. When the sound consists primarily of a single frequency there is a possibility that the diaphragm may be in resonance with this frequency. In this case a very large part of the sound energy is transmitted. Normally the resonance frequency of any part of a building is much lower than the frequencies of any of the ordinary sounds, and hence this condition will not generally be of importance." (The frequency of a 9-in. brick wall 11 ft. sq. is approximately 48 cycles per sec.)

As indicated in Chapter 6, sound intensities are measured in decibels. Fig. 7-22, reproduced from National Bureau of Standards Report BMS17, was made up from the results of various noise measurements and gives an approximate idea of the value of different noise levels in decibels.

The sound insulation required in a structure to give satisfactory results depends not only upon the noise level outside of the building or in adjoining

rooms but also upon the noise level within the room under consideration and the sound absorptive materials within the room.

If it is assumed that there is no noise within the room to be insulated against sound transmission and that the noise level in the adjoining room is 60 decibels, it will require a panel having a reduction factor of approximately 50 decibels to render the noise in the adjoining room inaudible. However, if the noise level in the room under consideration is 20 decibels, a panel having a sound reduction factor of approximately 40 decibels will make the sound in the adjoining room inaudible.

This effect of the sound within the room under consideration is known as the masking effect and, as described in BMS17, "is much the same as if the listener were partially deaf since his threshold of hearing is shifted slightly upwards."

Table 7-8 gives the maximum noise levels which should be tolerated in various occupancies as recommended by V. O. Knudsen in "Architectural Acoustics". Regarding these recommendations, the authors of BMS17 state:

TABLE 7-8

RECOMMENDED MAXIMUM NOISE LEVELS

Location	Maximum noise level which should be tolerated, Decibels
Studios for the recording of sound (talking picture studios)	6 to 8
Radio broadcasting studios	8 to 10
Hospitals	8 to 12
Music studios	10 to 15
Apartments, hotels, and homes	10 to 20
Theaters, churches, auditoriums, classrooms, and libraries	12 to 24
Talking-picture theaters	15 to 25
Private offices	20 to 30
Public offices, banking rooms, etc.	25 to 40

"Attention should be called to the fact that the above levels are those desired but seldom found in practice. Special attention is directed to the low noise level recommended for hospitals. This low level is desirable; but, because of the usual construction and location of hospitals, the level is generally very much higher."

The method of determining the peak noise level of rooms, the walls of which contain doors and windows, is described in BMS17 as follows:

"It can be shown that if E_1 is the energy level of the noise outside of a room, and E_2 the energy level in the room

$$\frac{E_1}{E_2}=\frac{A}{t_1s_1+t_2s_2+t_3s_3}, \qquad (1)$$

where A is the total absorption in the room, s_1, s_2, s_3, etc. are the areas of the various portions of the walls, such as walls, windows, etc., and t_1, t_2, t_3 are their respective coefficients of sound transmission or acoustic transmittivity; that is, the fraction of the incident sound energy that is transmitted through the panel. The value of t is seldom published. Instead, the value of $10 \log_{10} 1/t$, which is called the transmission loss in decibels, is given. The denominator

$(t_1s_1+t_2s_2+\ldots)$ is termed the total transmittance, and will be represented by T. Equation 1 can be rewritten

$$E_1/E_2 = A/T \qquad (2)$$

"The noise-reduction factor in decibels, which is the difference between the noise level outside of a room and the noise level in the room, is equal to

$$10\ (\log_{10}E_1 - \log_{10}E_2) = 10\ \log_{10}E_1/E_2 = 10\ \log_{10}A/T \qquad (3)$$

and the quantity 10 $\log_{10}A/T$ is called the noise reduction factor.

"To illustrate the use of these formulas and show the detrimental effect of doors and windows, let us assume the case of a brick buiding containing a single room. The walls are of 8-in. brick and the roof a 6-in. reinforced concrete slab. The total absorption in the room which has been acoustically treated is assumed to be 400 units. It is assumed also that the foundations and floor are built in such a manner that the amount of sound which enters the room through the floor is negligible. Assuming usual values for the transmission losses through the various parts, we may tabulate the separate items as follows:

Material	Areas, s sq. ft.	Transmission loss Decibels	t	ts
8-in. brick walls, plus plaster.........	1,200	54	0.0000040	0.0048
6-in. cement roof slab, plus plaster	600	50	.000010	.0060
Windows	150	28	.0016	.24
Door	21	35	.00032	.0067
Total transmittance, T, equals	....	....	....	0.2575

Noise-reduction factor (in decibels) $= 10 \log_{10} (A/T) = 10 \log_{10} (400/0.258) = 31.9$ decibels.

"From the last column in the above table it may be noted that the windows admit many times the amount of sound admitted by all of the wall and ceiling structures, and that the door admits more noise than either the walls or ceiling.

"If one window is open so that there is 1 sq. ft. of open window, the transmission loss through an opening like this is zero, hence $t = 1$ and $ts = 1$. In other words, an opening of 1 sq. ft. would transmit four times the sound energy that is transmitted by the entire structure with closed windows. The noise reduction factor with the partly opened window is diminished to 25.0 decibels.

"Frequently, the question arises as to how such a computation would be made in the case of an apartment room where one side is exposed to street noise, with adjoining rooms on two sides, and the fourth side adjacent to a corridor.

"Let us assume the case of a rectangular room, the width of which facing on the street is 10 ft., the length 12 ft., and the height 9 ft. Also, let us assume that the outer wall is a 13-in. brick wall having one window 3 x 5 ft., and that the interior walls are 4-in. clay tile plastered on both sides, having one door 3 x 7 ft., entering from the corridor. Assume the street noise to be 80 decibels, the peak noises caused by loud talking and laughter in the room on one side to be 75 decibels, the peak noise in the other room to be 60 decibels, and in the corridor, 60 decibels. We shall neglect all sound coming through the floor or ceiling. The total absorption by carpet, draperies, furniture, etc., will be considered as 70 units.

"If the noise-reduction factor for each wall is computed as before, the following is obtained:

EXTERIOR WALL

Material	Areas, s sq. ft.	Trans-mission loss Decibels	t	ts
13-in. brick wall, plus plaster on one side	75	57	0.0000020	0.00015
Window	15	28	.0016	.0240
Total transmittance, T, equals	....	....	....	0.0242

Noise-reduction factor (in decibels) = 10 $\log_{10}$ (A/T) = 10 $\log_{10}$ (70/0.0242) = 34.6 decibels.

WALL BETWEEN ROOMS

Material	Areas, s sq. ft.	Trans-mission loss Decibels	t	ts
4-in. clay tile wall, plus plaster on both sides	108	44.0	0.000040	0.00432
Total transmittance, T, equals	....	....	....	0.0043

Noise-reduction factor (in decibels) = 10 $\log_{10}$ (70/0.0043) = 42.1 decibels.

WALL BETWEEN ROOM AND CORRIDOR

Material	Areas, s sq. ft.	Trans-mission loss Decibels	t	ts
4-in. clay tile wall plus plaster on both sides	69	44.0	0.000040	0.0028
Door	21	35.0	.00032	.0067
Total transmittance, T, equals	....	....	....	0.0095

Noise-reduction factor (in decibels) = 10 $\log_{10}$ (70/0.0095) = 38.7 decibels.

"The noise in the room caused by street noise only would be 80.0−34.6 = 45.4 decibels. That from the noisiest room would be 75−42.1 = 32.9 decibels. That from the quietest room, 60−42.1 = 17.9 decibels, and that from the corridor, 60−38.7 = 21.3 decibels.

"The approximate peak noise level can be obtained as follows:

$$\begin{aligned} \text{Anti} \log_{10} (45.4/10) &= 34700 \\ \text{Anti} \log_{10} (32.9/10) &= 1950 \\ \text{Anti} \log_{10} (17.9/10) &= 60 \\ \text{Anti} \log_{10} (21.3/10) &= 140 \\ \hline & \quad 36850 \end{aligned}$$

$$10 \log_{10} 36850 = 45.7 \text{ decibels.}$$

"In other words, the street noise, because of the poor insulation of the window, is the predominating noise, but it may not be the most annoying one, as the intermittent noise resulting from loud talking and laughing may be

more disturbing than a steady noise. Furthermore, with a level of 32.9 decibels it should be possible to understand a large portion of any conversation carried on in the adjoining room.

"The values given for transmission losses are approximate for doors and windows, and are used merely to illustrate the fact that with a door or window in a wall it may be impractical to attempt to make the rest of the wall a good sound insulator, inasmuch as a small opening, such as a crack under a door, will greatly reduce the sound insulation. The same is true of ducts or any other opening which may connect two rooms.

"In equation 3 the total absorption comes in the numerator, hence the noise level can be reduced by increasing the total absorption in the room. Generally, however, this reduction is not large, being of the order of about 5 decibels as between a treated and an untreated room. This means that the introduction of absorbent material to reduce the noise level caused by noises originating outside of the room is of little value, since a much greater reduction can generally be obtained at less cost by increasing the sound insulation of the boundaries of the room. This does not mean that sound absorbent materials are of no value, for they are necessary to keep down the noise level resulting from noises originating in the room. Absorbent material prevents corridors from acting as speaking tubes and transmitting sound from one room to another when the doors are open. Other illustrations could be given of the value of sound absorption, but the fact should be emphasized that sound absorption cannot take the place of sound insulation."

Sound reduction factors for various walls and partitions are given in Table 6-24, Section 607, Chapter 6.

720. THERMAL INSULATION

The amount of thermal insulation which will be built into walls will depend upon economical considerations and, in the case of buildings designed for human habitation, considerations of comfort. In buildings for which the walls are insulated to prevent the flow of heat from the interior to the exterior, estimated savings in heating costs may be used as a guide in determining the amount of insulation which may economically be installed.

In addition to this factor, however, the surface temperatures of walls affect the comfort of the inhabitants, particularly in dwellings where the occupants frequently are not actively engaged in work. Cold surfaces absorb radiant heat from the body just as fireplaces and warm radiators project heat to the body. If the wall or floor surfaces are cold, they produce a feeling of chill even if the room air is 70° F. or thereabout. This comfort factor may dictate the use of insulation which could not be justified by economical considerations.

Heat losses and surface temperatures are determined by the thermal coefficients of the structural elements (walls, floors, windows, etc.) enclosing the room, which may be computed from the coefficients listed in Table 6-22, Section 606, Chapter 6.

In computing thermal coefficients of walls, however, it should be borne in mind that coefficients of conductance of many building materials vary over a fairly wide range and that the coefficients listed in Table 6-22 are of necessity averages. For this reason, too much importance should not be attached to relatively slight variations in the computed resistances.

It should also be noted that for insulated walls, relatively large variations in the conductances of the structural materials have only a small effect on total resistance.

Tests reported in National Bureau of Standards Research Paper 291, "Heat Transfer Through Building Walls", by M. S. VanDusen and J. L. Fink, include the following wall constructions:

Nine brick walls, 8 and 12 in. thick, both solid and hollow

Four hollow tile walls:

- 8x12x12 single shell load-bearing tile, 2 cells in wall thickness, end construction
- 8x12x12 single shell load-bearing tile, 2 cells in wall thickness, side construction
- 5x8x12 double shell load-bearing tile, 2 cells in wall thickness, end construction
- 2-unit wall constructed of 4x12x12 load-bearing tile, 1 cell each in wall thickness, end construction

One 8-in. concrete block wall.

Two 4-in. frame walls.

Based on the tests of these walls, the authors conclude:

"In general, the presence of air spaces or pockets increases the insulating value of walls built of heavy clay products.

"Furring materially increases the insulating value of ordinary types of walls.

"The differences in insulating value between the various types of hollow tile walls tested are unimportant.

"Judging by tests on two kinds of brick, representing approximately the two extremes in common brick manufacture, the kind of brick used in a brick wall is of little importance from the insulation standpoint alone.

"The type of workmanship in a masonry wall may make a considerable difference in the insulating value, depending chiefly on the degree of filling of the mortar joints. Solidly filled vertical joints are not so effective from the insulation standpoint as partially filled joints.

"The insulating value of all walls tested increases with decreasing temperature, the increase, in general, being more rapid with hollow walls than with solid walls.

"In conclusion, it might, perhaps, be emphasized that in an actual building, heat loss through windows, doors, and roof tend to level out the effect of differences in the walls themselves to a very considerable extent. It may, therefore, be said that although there are considerable differences in the insulating values of the various types of walls tested, the magnitude of these differences is not sufficient to make them a very important factor in the choice of building wall types, except, perhaps, in the case of relatively thin solid masonry without air spaces, where discomfort may be caused or moisture condensation produced by abnormally cold interior wall surfaces."

During World War II the War Production Board issued various orders, affecting construction, designed to conserve critical materials. Among these orders was the Housing Critical List which included the requirement that the maximum total hourly heat loss of a dwelling should not exceed in any case 60 times the gross floor area in square feet, measured at each principal floor level, or 80,000 Btu per dwelling unit, whichever is the smaller, and should be determined in accordance with the data and methods described in the

current edition of the "Guide" of the American Society of Heating and Ventilating Engineers, or by an alternate method which results in not less than the amount determined by the Guide method; such hourly heat losses to be based on maintaining 70° F. inside the dwelling when the outside temperature is at the design temperature for the locality.

In general, the method of determining total heat loss is to compute the heat flow through roof, floor and exterior walls, windows and doors, to which is added the equivalent heat loss due to infiltration of cold air. However, as a means of checking plans for dwellings against the War Production Board's requirement, a short method of calculating total hourly heat loss was developed which is accurate to within 10 per cent or less when applied to small dwellings of typical design. A description of this method is contained in the 1949 edition of the American Society of Heating and Ventilating Engineers' Guide in the discussion of "Fuel Consumption." The following formulae are employed:

$$H_1 = A(G + U_w + U_c + U_f)\ (70 - t_o)$$
$$H_2 = A(G + 1.2\ U_w + 0.5\ U_c + 0.5\ U_f)\ (70 - t_o)$$

where H_1 = heat loss from 1 story residence, Btu per hour

H_2 = heat loss from 1½ or 2 story residence, Btu per hour

A = interior floor area in square feet or $\dfrac{\text{gross floor area in square feet}}{1.10}$

G = glass and infiltration factor for ordinary construction:
= 0.45 for no weatherstripping or storm windows
= 0.40 for weatherstripping
= 0.30 for storm windows with or without weatherstripping

U_w = coefficient of transmission for outside wall

U_c = coefficient of transmission for ceiling

U_f = coefficient of transmission for floor

t_o = outside design temperature, degrees Fahrenheit.

Note:
1. Consider attics, basementless spaces, and unheated garages to be at outside design temperature.
2. For all floors over basements or other warmed spaces assume $U_f = 0$.
3. For structures having slab floors laid on the ground a modified application of the formula may be made. Assume $U_f = 0$ and calculate the heat loss in accordance with the short-cut formula. Then add the slab loss based on the perimeter of exposed edge of the floor determined by the formula:

$$S = kDp$$

Where S = total slab heat loss in Btu per hour.

D = maximum degree days in one calendar month. For maximum heat loss use calendar month having greatest number of degree days.

p = exterior exposed perimeter of floor slab in feet.

k = heat loss factor in Btu per hour for each lineal foot of exposed edge of floor per degree day during 30 consecutive days.

Values of k for various floor slabs have been determined by test and are reported in National Bureau of Standards Report, BMS103, and by the University of Illinois, Small Homes Council. In the absence of a coefficient determined by test, 0.025 may be assumed as an average value of k for 4- to 6-in. thick slabs separated from the foundation by vertical insulation 1 in. thick.

As an example of the application of these formulae, assume that it is required to determine the design heat loss for a one-story basementless detached house having a gross area of 880 sq. ft. and located in a 0° F. design temperature. The drawings and specifications show that the construction is to be as follows:

Glass—Storm windows	G	$= 0.30$
Wall—8 in. Brick and Tile—furred with ½ in. plaster on ⅜ in. plasterboard	U_w	$= 0.27$
Ceiling—Plaster on plasterboard with 2 in. blanket insulation	U_c	$= 0.10$
Floor—Ordinary double floor—no insulation	U_f	$= 0.28$
	Total	$= 0.95$

Floor area "A" $= \dfrac{880}{1.10} = 800$ sq. ft.
(interior floor area)

$H_1 = A(G + U_w + U_c + U_f)\ (70 - t_o)$
$H_1 = 800 \times 0.95 \times (70 - 0)$
$= 53{,}200$ Btu—approximate hourly heat loss.

Yearly fuel consumption may be computed by what is known as the degree-day method. A degree-day is a unit based upon temperature difference and time used in specifying the normal heating load in winter. For any one calendar day there exists as many degree days as there are degrees Fahrenheit difference in temperature between the mean temperature for the calendar day and 65° F.; one degree below 65° F. for a 24-hr. period equals one degree-day. This is based on the assumption that no artificial heat is required when the mean daily outside temperature is 65° F.

Degree-days may be obtained from the United States Weather Bureau reports for most cities in the United States and Canada. A condensed list is given in the American Society for Heating and Ventilating Engineers' Guide.

The design temperature for any area is the minimum recommended outside temperature used in determining the capacity of heating equipment required to maintain an inside temperature of 70° F. A list of recommended design temperatures for various cities is given in the ASHVE Guide.

The degree-day formula for determining fuel consumption is:

$$F = \frac{H(24D)}{(t_d - t_o)E.C} \qquad (1)$$

where F = Fuel consumption for estimate period
H = Calculated heat loss (Btu per hour)
D = Number of degree-days for the estimate period
t_d = Inside design temperature
t_o = Outside design temperature
E = Efficiency of fuel utilization
C = Heating value of fuel.

As an example of the application of this formula, we will determine the yearly fuel consumption for the house described in the preceding example for which the following values are known or assumed:

H, total hourly heat loss .... = 53,200 Btu
D, number of degree-days .... = 6,000
t_d, inside design temperature .... = 70° F.
t_o, outside design temperature .... = 0° F.
E, efficiency of fuel utilization .... = 60%
C, heating value of fuel (assume oil) .... = 144,000 Btu per gal.
Substituting in formula (1)

$$F = \frac{53{,}200 \times 24 \times 6000}{70 \times .60 \times 144{,}000} = 1267 \text{ gal. of oil.}$$

The following are the average heating values for various fuels:
Oil—144,000 Btu per gal.
Coal—Anthracite—14,000 Btu per lb.
Bituminous—12,000 Btu per lb.
Gas—Natural—1100 Btu per cu. ft.
Artificial—535 Btu per cu. ft.

721. DAMPNESS ON INSIDE WALLS

Technical Bulletin TIBM-25 of the National Bureau of Standards contains the following regarding the value of plastering:

"The occupant of a building is constantly aware of the quality of plaster on walls and ceiling through daily impressions, made subconsciously upon his mind perhaps, by which he becomes cognizant of whatever faults or merits it may possess. To him, its obvious value is that of decoration, although it has other functions which, though none the less important, are frequently lost sight of."

Moisture on interior walls, even in small quantities, tends to destroy wall decorations and in larger amounts may result in the failure of the plaster. Regardless of the actual damage occasioned by the moisture, its appearance inevitably results in a dissatisfied tenant and frequently the elimination of the cause of the trouble is an inconvenient and expensive operation.

Damp inside walls are not peculiar to any type of construction nor to any building material but usually result from one of the following causes: leakage through exterior walls or roof, condensation either on the wall surface or within the wall, or presence of hygroscopic salts in the plaster.

When the moisture appearing on the inside of a wall is due to leakage, the water has percolated through the plaster. This action softens the plaster and tends to loosen it from the lath or surface to which it is applied. Details of the design and construction of masonry structures, which should be followed to eliminate leakage, are discussed elsewhere.

(a) Condensation. Atmospheric air is a mixture of dry air and water vapor. At a given temperature air is saturated when the space occupied by the mixture holds the maximum possible weight of water vapor at that temperature. The amount of water vapor necessary to saturate the air at constant pressure depends upon the temperature—the higher the temperature the more water vapor will be required. If saturated air at a temperature of 50°, for instance, is warmed to a temperature of 70°, the mixture is no longer saturated but will absorb additional water vapor. However, if an unsaturated

air is cooled at constant pressure, a temperature will be reached at which the air is saturated. This temperature is called the dew point and if the mixture is cooled below the dew point, water will condense from the air. Dew which occurs in the early mornings during the warmer months in many localities is one of the most common examples of the effect of cooling unsaturated air to a temperature below the dew point or to a point where the water vapor which the air contains begins to condense.

The water vapor in air is called humidity, and relative humidity is the ratio of the amount of water vapor which a mixture contains to the amount required for saturation at a given temperature. Obviously, for a fixed amount of water vapor, the relative humidity will vary with the temperature, increasing as the temperature is lowered and decreasing as the temperature rises.

While the dew point depends upon the amount of water vapor in the air and is the temperature at which the water vapor present is sufficient for saturation, there is also a practically constant relation between dew point and relative humidity for a considerable range of temperatures. That is, for a relative humidity of 50 per cent the difference between air temperature and dew point is approximately 20° for any air temperature from 60° to 90°. Similar relations hold for other relative humidities. A discussion of the reason for this relationship may be found in the American Society of Heating and Ventilating Engineers' Guide.

In Fig. 7-23, the difference in temperature between the air and the dew point (temperature drop) is plotted for relative humidities from 50 per cent to 100 per cent. It will be noted from this curve that for relative humidities above 80 per cent a drop in temperature of 6.8° or over will cause condensation. These high humidities usually occur during the summer when the difference in temperature between the air on opposite sides of a wall is small, probably 10° or less. For walls below grade, the temperature difference of the two sides of the wall may amount to 20° or more.

If condensation occurs on walls, it will appear during periods of high relative humidities or during extremely cold weather when there is a large difference in temperature between inside and outside air.

For a relative humidity of 60 per cent, the temperature drop necessary to produce condensation is 15°, however, in residences the relative humidity may reach a value above 60 per cent due to the introduction of water vapor into the air in the form of steam from cooking or other sources. If condensation occurs it may be eliminated by:

(1) Reducing the humidity of the air. This may be accomplished by adequate ventilation if the high humidity is caused by conditions inside the building.

(2) Increasing the temperature of the surface upon which the condensation occurs. Probably the simplest means of increasing the surface temperature is to increase the movement of air over the surface.

(3) Increasing the heat resistance of the wall. This is usually done by the addition of an air space back of the plaster.

Table 7-9 gives the difference in temperature between the inside surface of various types of walls and the inside air temperature for differences between inside and outside air, ranging from 10° to 70° F. These figures are based upon the conductivities and conductances of materials listed in Table 6-22, Chapter 6.

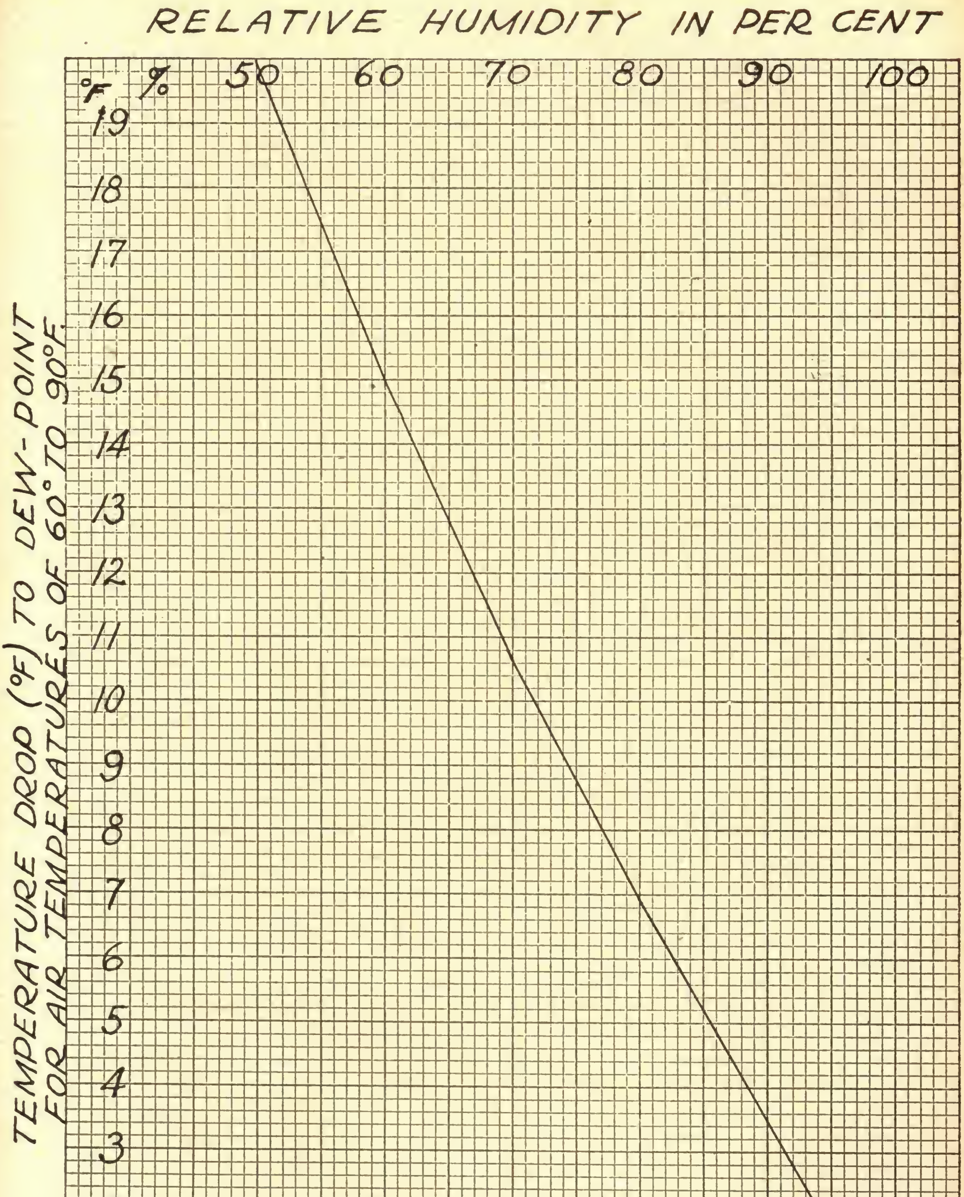


FIG. 7-23

Temperature drop curve for relative humidities from 50 per cent to 100 per cent.

TABLE 7-9

DIFFERENCE IN TEMPERATURE BETWEEN INSIDE AIR AND INSIDE WALL SURFACE FOR VARIOUS TOTAL DIFFERENCES IN TEMPERATURE BETWEEN INSIDE AIR AND OUTSIDE AIR

	Difference in temperature between inside and outside air °F.						
	10	20	30	40	50	60	70
8″ solid brick, plastered....	3	6	9	12	15	18	21
8″ solid brick, furred and plastered	2	4	6	8	10½	12½	14½
4″ brick, 4″ tile, plastered..	2½	5	7	9½	12	14½	16½
4″ brick, 4″ tile, furred and plastered	2	3½	5	7	9	10½	12½
8″ hollow tile, plastered; average tile.............	2	4	6	8	10	12	14
2 cells in direction of heat flow	2½	4½	7	9	11½	13½	16
3-cell, divided mortar joints	1½	3½	5	7	8½	10½	12
8″ hollow tile, furred and plastered; average tile ..	1½	3	4½	6	7½	9	10½
2 cells in direction of heat flow	1½	3½	5	7	8½	10	12
3-cell, divided mortar joint	1½	3	4	5½	7	8½	9½
Cavity wall, 4″ brick, 4″ tile, plastered	2	3½	5½	7	9	10½	12½

From Table 7-9, it will be noted that for a difference in temperature between inside and outside air of 60°, the inside temperature of an 8-in. average tile wall plastered direct would be 12° below the temperature of the inside air. Referring to the curve, a temperature drop of 12° will not cause condensation for relative humidities of 67 per cent or under.

Temperature ranges in various localities may be obtained from the National Weather Bureau and, if the designer can determine the relative humidity that will be maintained within a building, the above table may be used in conjunction with the "temperature drop" curve to select a type of wall construction which will be free from condensation.

(b) Hygroscopic Salts in the Plaster. Hygroscopic salt is a substance which will absorb water from the air. One of the best known of such salts is calcium chloride which is frequently used to keep down the dust on roads, parking lots, and similar areas and is sometimes used in curing concrete. If an appreciable quantity of ordinary table salt (sodium chloride) is introduced into plaster, the calcium either as lime or gypsum will combine with the salt and form calcium chloride. In a rather dilute form, it is not as active as the pure calcium chloride; however, during periods of high relative humidity, it will absorb sufficient moisture from the air to stain the wall paper or other decoration which may have been applied to the plaster.

If the moisture which appears on a wall is due to hygroscopic salts in the plaster, the moisture comes from the air inside of the room and does not penetrate the plaster. Consequently, the danger of falling plaster is minimized and the condition of the plaster may serve as a guide to the source of the moisture.

722. CONDENSATION IN BUILDING WALLS

Studies of the causes and prevention of condensation in building structures, made by L. V. Teesdale at the Forest Products Laboratory, Frank B. Rowley at the University of Minnesota, and by the Housing and Home Finance Agency under the direction of Leonard Haeger at Pennsylvania State College, have shown that dampness in the structural and enclosing elements of heated buildings due solely to condensation can largely be eliminated by simple means.

Condensation is due to moisture originating inside the buildings. The moisture content of outside air which enters the building and is heated for comfort purposes is invariably increased by moisture released from cooking, bathing, washing, and other operations employing water or steam, and by moisture released by exhalation and perspiration from the occupants. This gain in the moisture content of the air increases the vapor pressure substantially above that existing in the outdoor atmosphere, and therefore this pressure tends to drive the vapor outwardly from the building through any vapor porous materials that may comprise the enclosing surfaces.

Vapor will move independently of air. The vapor movement through common building materials, including brick, structural tile, plaster, wall boards and most building insulation materials, is at a relatively high rate, but some materials, such as high grade sheathing papers, hot coatings of asphalt, aluminum and copper foils, aluminum and other heavy bodied paints in two or more coats, have high vapor resistance or may be completely impermeable.

When vapor passes through porous and homogeneous materials which may be warm on one side and cold on the other, it may pass through the zone of its dew-point temperature without condensing into water. But if the flow of vapor is impeded by vapor resistant surfaces at a temperature below the dew-point temperature the vapor will condense upon such cold surfaces.

Since the phenomenon of condensation is due to a natural movement of vapor retarded in the cold side of the dew-point zone by relatively vapor resistant surfaces, the prevention of condensation can be achieved by either or both of two simple methods. The first method is to employ vapor resistant materials on the warm side of the enclosing structure to prevent the vapor generated indoors from reaching its dew-point temperature within the structure. For this purpose various materials, known as vapor barriers, should be used. Building insulation materials of the blanket or bat type are now commercially supplied with a vapor barrier paper on one side. This paper, of course, is installed toward the warm side of the insulation. Loose fill insulation, insulating boards, or uninsulated air spaces may be effectively protected by the use of sheathing papers known to have a high vapor resistance. These include papers having a glossy asphalt coat, papers containing aluminum or copper foil, and certain types of papers which have an impervious wax treatment on the surface.

The second method of preventing condensation is to provide relatively free venting of the cold side of the construction to the outer air, either by employment of vapor porous materials or by the actual provision of free vents through which both air and vapor may move. Such open vents, in the form of louvers, are commonly recommended for attic and roof spaces in all types

of structures as such venting not only relieves the vapor condition in winter but also contributes to summer comfort.

For reasons already explained, exterior coatings designed to prevent dampness in masonry walls are undesirable if the dampness is due in part or in whole to vapor movement and condensation. Vapor pressures are sufficient to eventually blister impervious films applied to the exterior surface. If they fail to break through such films the condensation and moisture condition is actually aggravated. Such film should only be used in extreme cases when it is also possible to provide superior vapor resistance on the warm side of the construction.

723. CRACKING OF MASONRY WALLS

Horizontal cracks in masonry walls of load-bearing structures supporting reinforced concrete slabs have been observed in many buildings and, at the request of the Federal Public Housing Administration, the National Bureau of Standards undertook a study of the factors contributing to this type of wall cracking. During the course of this study, a building was constructed with load-bearing masonry walls supporting a concrete roof slab and movements of the wall and slab were measured and recorded.

As a result of this investigation these cracks are believed to be the result of two types of movement of the slabs; namely, curling and horizontal shrinkage.

Slabs, originally plane, tend to warp by an upward movement at and near the corners with a downward deflection of the interior portions. This change in shape of slabs supported along four edges is a typical behavior and is produced by the following three causes:

1. Deflections under distributed dead and live loads resulting from elastic and plastic deformations. An upward movement of the corners accompanies the downward deflection of the interior.

2. The shrinkage of the concrete in the slab being partially restrained by reinforcement near the lower surface causes the upper surface to become concave.

3. Slabs supported at the edges on masonry walls and in the interior by concrete columns are caused to deflect by the lowering of the interior supports resulting from the shrinkage of the concrete columns.

The shrinkage of the concrete slabs in a horizontal direction tends to pull the supporting walls toward the interior of the building. At corners, the walls are buttressed against this movement by the intersecting walls, but elsewhere the walls are pulled in by the slab by amounts that are readily measurable. As the walls upon which the slabs rest are pulled inward, and as the wall above a horizontal crack is not subjected to this force, it is often noticed that the portion of a wall below a crack is not in the same vertical plane with that above the crack.

The methods of preventing or controlling the horizontal cracks, caused by slab movement, that appear to have merit include the following:

1. Spandrel beams monolithic with the slab,

2. Continuous columns of reinforced concrete at the corners of slabs,

3. Allowing the slabs to dry before the construction of the portions of a wall that are above the slab.

CHAPTER 8

BRICK AND TILE WALL SECTIONS AND DETAILS

801. GENERAL

When the terms brick and tile are used in this chapter they should be understood to mean brick and solid masonry units and structural clay tile and hollow masonry units, respectively.

A solid masonry unit is one whose net cross-sectional area in every plane parallel to the bearing surface is 75 per cent or more of its gross cross-sectional area measured in the same plane.

A hollow masonry unit is one whose net cross-sectional area in any plane parallel to the bearing surface is less than 75 per cent of its gross cross-sectional area measured in the same plane.

Brick and tile walls may be classified according to types of construction, as solid masonry walls, hollow masonry walls, cavity walls, faced or composite walls, and veneered walls.

Solid masonry walls consist of masonry units laid contiguously with the joints between the units filled with mortar. Solid masonry walls may be built of either solid or hollow masonry units in any required thickness for both load-bearing and non-load-bearing construction.

Hollow masonry walls are built of masonry units so arranged as to provide air spaces in the wall and in which the facing and backing of the wall are bonded together with masonry units. Hollow masonry walls are usually constructed of solid masonry units, although in some instances the backing may be of hollow masonry units. They are relatively light in weight, are highly fire resistive and may present the same exterior appearance as solid masonry walls.

Cavity walls are built of masonry units so arranged as to provide a continuous air space within the wall and in which the facing and backing are tied together with metal ties. Cavity walls may be built entirely of either solid or hollow masonry units or of a combination of the two. The continuous cavity reduces the heat transmission of the wall below that of solid masonry walls and provides an effective barrier against moisture penetration. This type of wall is becoming increasingly popular, particularly in areas where the resistance to rain penetration may be a problem.

Faced or composite walls are walls in which the masonry facing and backing are of different types, but so bonded as to exert common action under load. This is perhaps the most common type of wall construction in use at the present time (1950) and is usually built with the exterior facing of brick and back-up of hollow masonry units.

Veneered walls are walls having a masonry facing which is attached to the backing but not so bonded as to exert common action under load. Masonry veneering may be brick or tile; however, brick is more commonly used, particularly in residential building where the backing is customarily

frame construction. Masonry veneer may be attached to walls of masonry, reinforced concrete or various types of panel construction.

802. SOLID BRICK WALLS

Solid brick walls are perhaps the oldest type of masonry construction known to man. They have been and are still used extensively for bearing walls in load-bearing construction, fire walls and reinforced brick masonry walls. Prior to the general use of skeleton frame construction, load-bearing solid brick walls were built to heights in excess of 10 stories; an outstanding example being the Monadnock Building in Chicago which is 24 stories high with masonry foundation walls 4 ft. thick. Current practice, however, is to

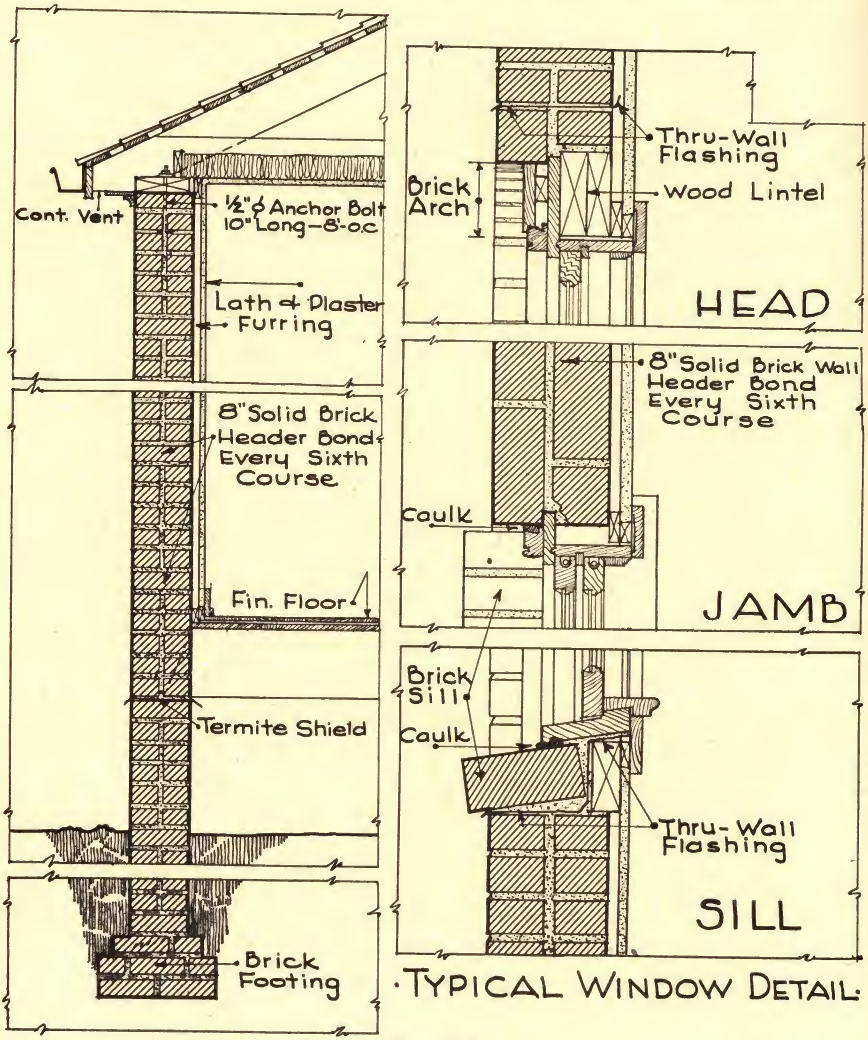


FIG. 8-1

Typical section and details of 8-in solid brick wall

limit the height of load-bearing walls to not over 6 stories for economic reasons.

Figs. 8-1 and 8-2 show typical wall sections and details of 8-in. and 12-in. solid brick walls.

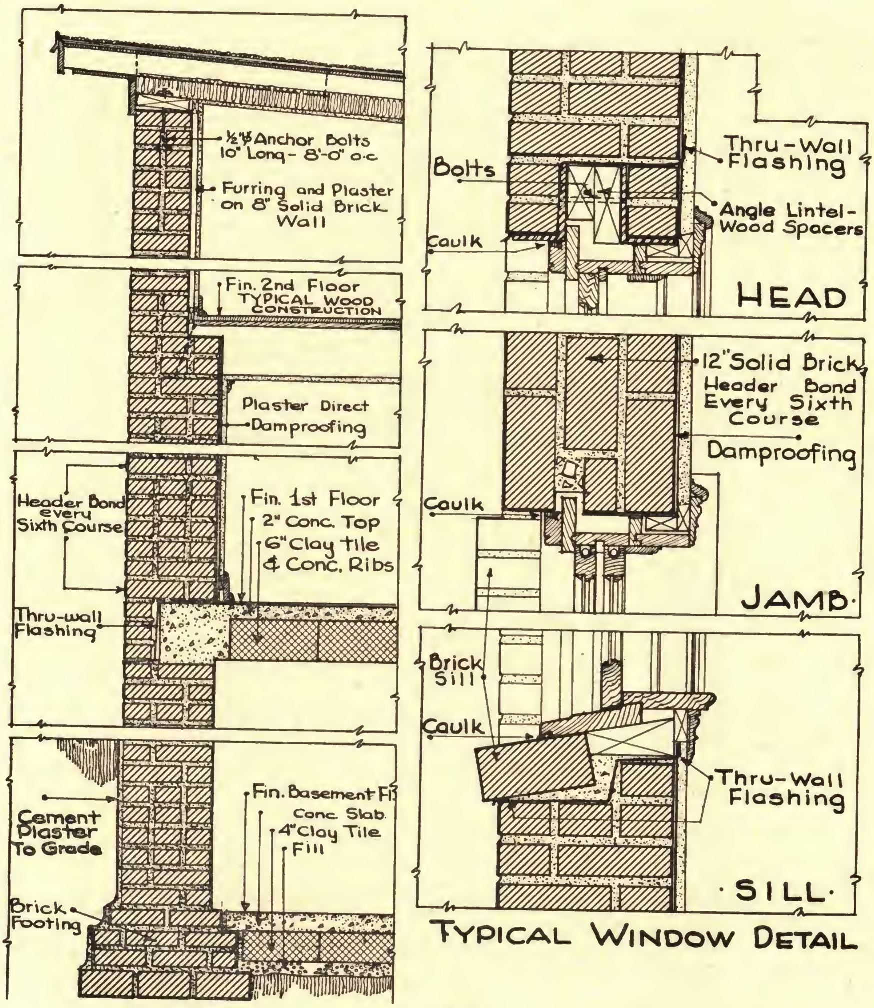


FIG. 8-2

Typical section and details of 12-in solid brick wall

803. ROLOK-BAK WALLS

The Rolok-bak wall is a general utility wall and may be employed for exposed or unexposed walls and for basement construction. The exterior wythe, or 4-in. thickness, is laid with the brick flat in the exposed face, therefore has the appearance of brickwork laid in the usual way and may be faced in any bond or pattern. The backing wythes are laid with brick on edge and bond is obtained by means of header courses at regular intervals.

The nominal thicknesses of Rolok-bak walls may be 8 in. or in multiples

of additional 4-in. thicknesses. In the 12-in. thickness, there are two types of construction—standard and heavy-duty.

The standard 12-in. wall is designed for bearing walls of buildings where 12-in. walls are required and floor loads are moderate, such as apartments, hospitals, clubs, offices, etc. In this wall, the wythes are bonded every seventh course with brick laid in basket weave.

The heavy duty 12-in. wall is designed for the support of heavy floor loads and differs from the standard wall in the manner of bonding. The fourth course of the inner wythes (on edge) becomes a continuous rolok header course bonding the two inner wythes. The next course is laid flat to form a continuous header course bonding the outer wythe and backed by a stretcher course on the inner face.

Fig. 8-3 shows typical wall section and details of an 8-in. rolok-bak

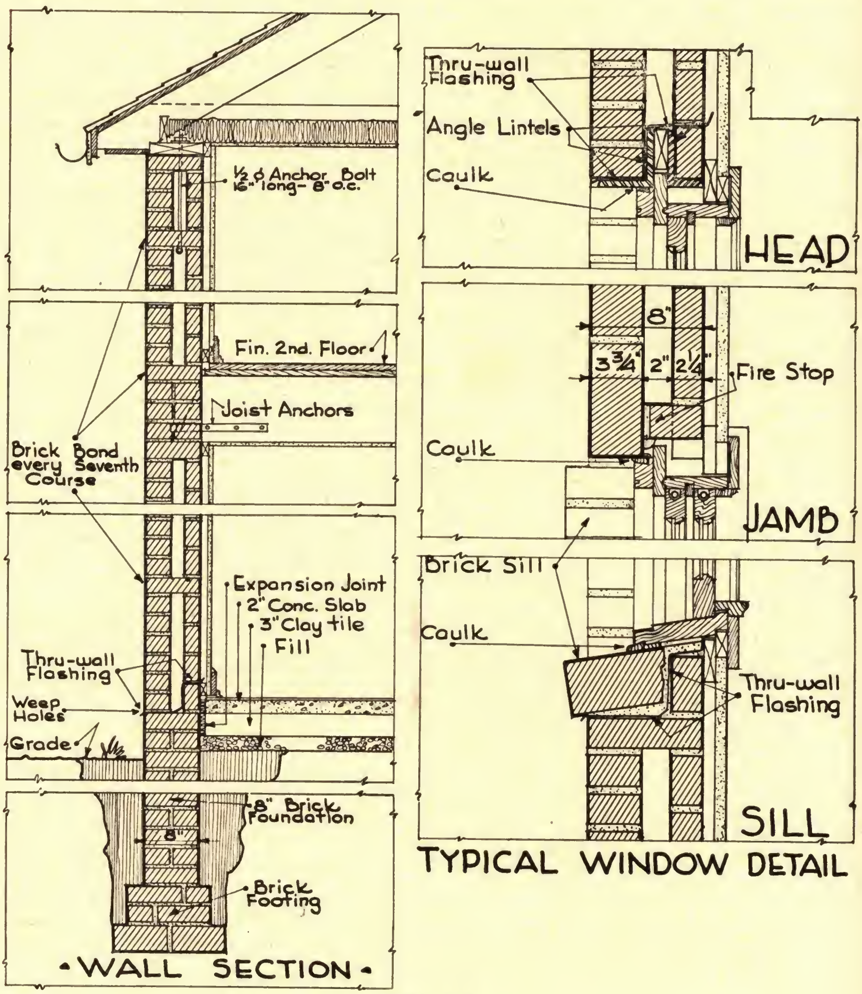


FIG. 8-3

Typical section and details of 8-in rolok-bak wall

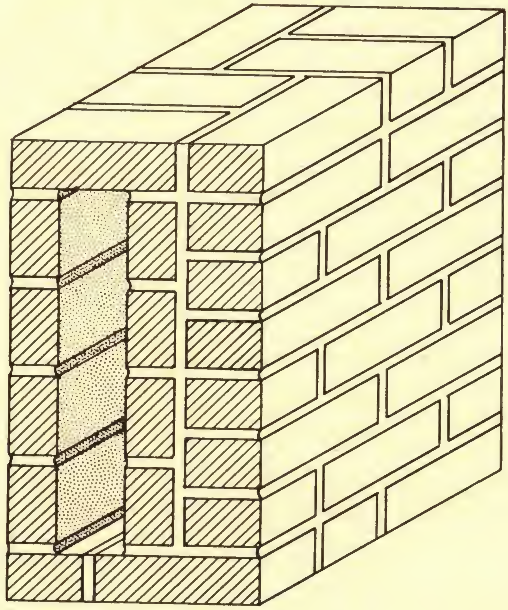


FIG. 8-4

Standard 12-in rolok-bak wall

wall and Figs. 8-4 and 8-5 illustrate the method of constructing the standard and heavy-duty 12-in. rolok-bak walls, respectively.

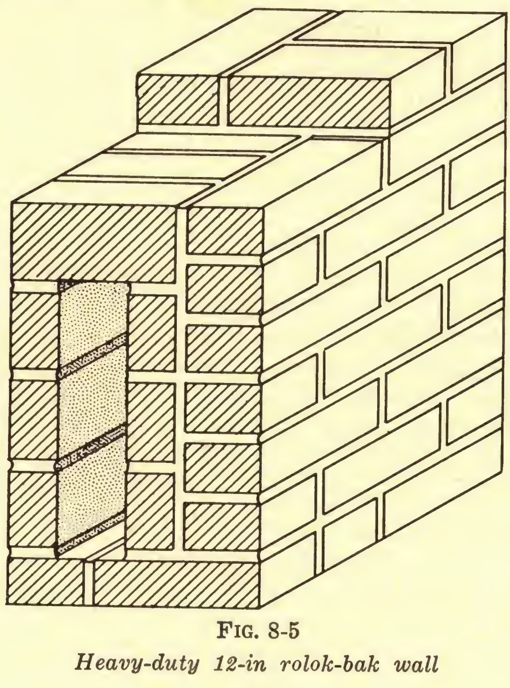


FIG. 8-5

Heavy-duty 12-in rolok-bak wall

804. ALL-ROLOK COMMON BOND WALLS

All-rolok walls may be used for exposed and unexposed bearing or non-bearing walls. They are low in cost and light in weight and afford an opportunity to effect savings in the amount of steel required for the support of walls in skeleton frame construction.

The type of wall may be 8 in. in thickness or greater, increasing by multiples of 4 in. The wall is constructed by laying up all wythes with brick on edge, with two courses of stretchers on edge alternating with one continuous header bond course laid flat. The bond course is laid in basket weave pattern in the 12-in. wall, and the center wythe is placed not at the center of the wall, but at the end of the headers which show on the exterior face of the wall.

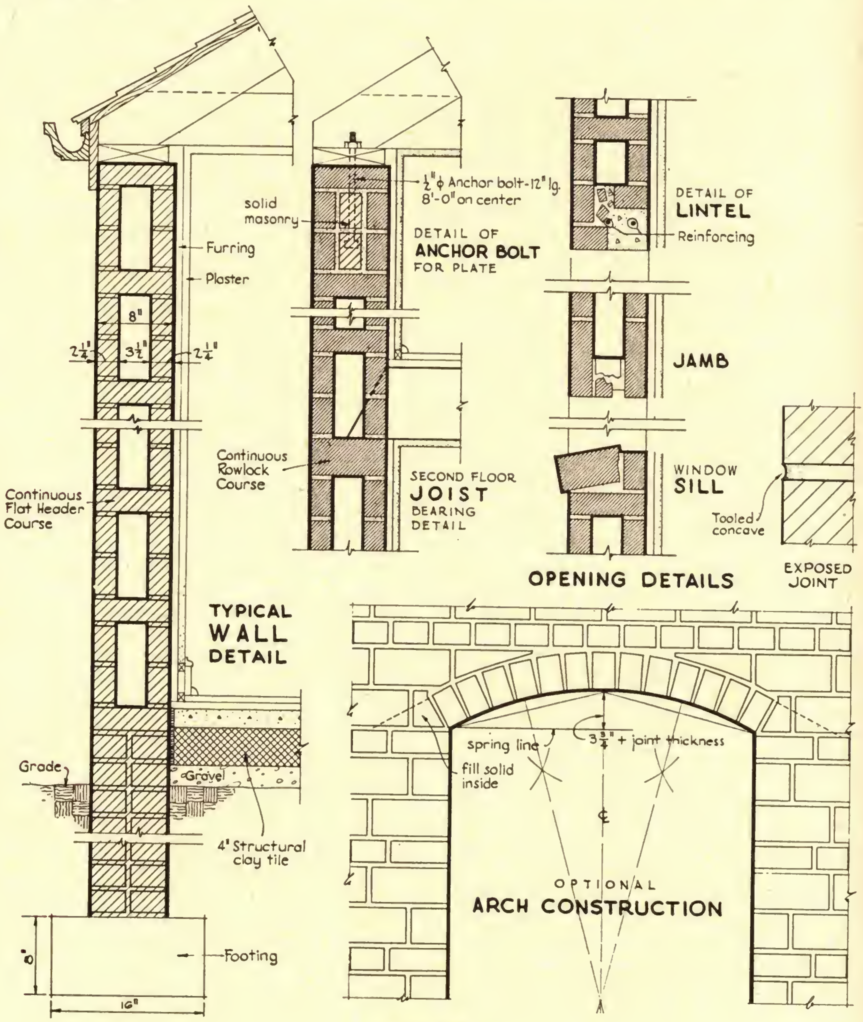


FIG. 8-6

8-in. all-rolok wall—common bond

Fig. 8-6 shows typical wall section and details of an 8-in. all-rolok common bond wall, and Fig. 8-7 illustrates methods of constructing the 12-in. all-rolok common bond wall.

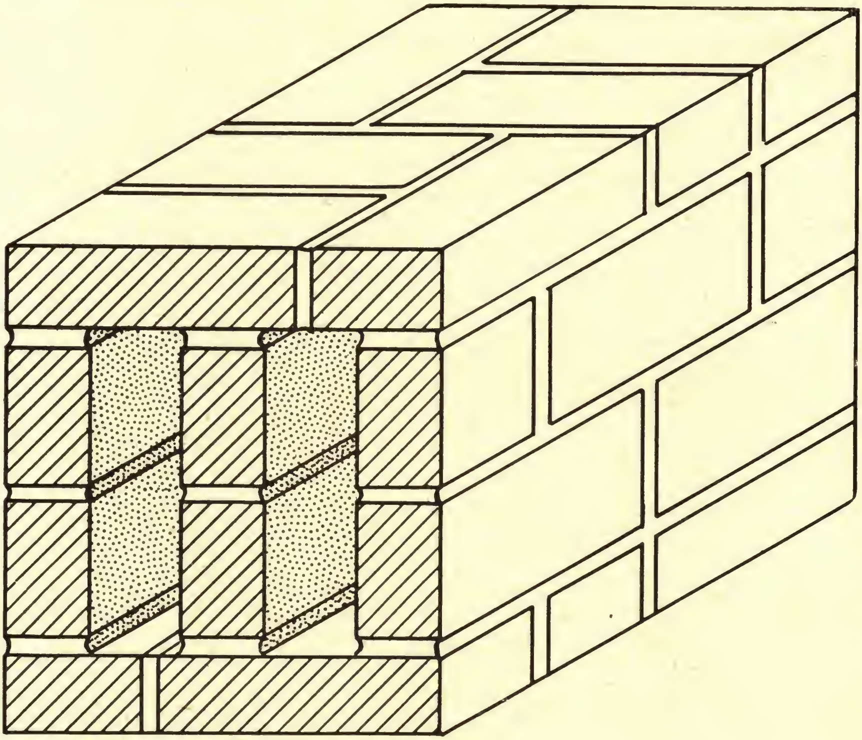


FIG. 8-7

12-in all-rolok wall—common bond

805. ALL-ROLOK FLEMISH BOND WALLS

This wall, because of its appearance, is intended primarily for exposed walls. It is very strong and consequently may be used for interior and basement walls. It is constructed entirely of brick on edge in Flemish bond for the outside 8-in. thickness.

The 8-in. wall is built of alternate stretchers and headers, backing up at every course. Headers in each course are placed over the center of the stretchers of the course below and should be carefully lined up vertically for the height of the wall.

For thicker walls, a wythe of stretchers is added for each additional 4-in. thickness. The inner wythe is built three courses high, on which is laid a continuous rolok bond course opposite which, on the exterior wythe, is laid a course of stretchers and bats to preserve the Flemish bond.

Fig. 8-8 shows wall section and details of an 8-in. all-rolok Flemish bond wall, and Fig. 8-9 illustrates the method of constructing the 12-in. all-rolok Flemish bond wall.

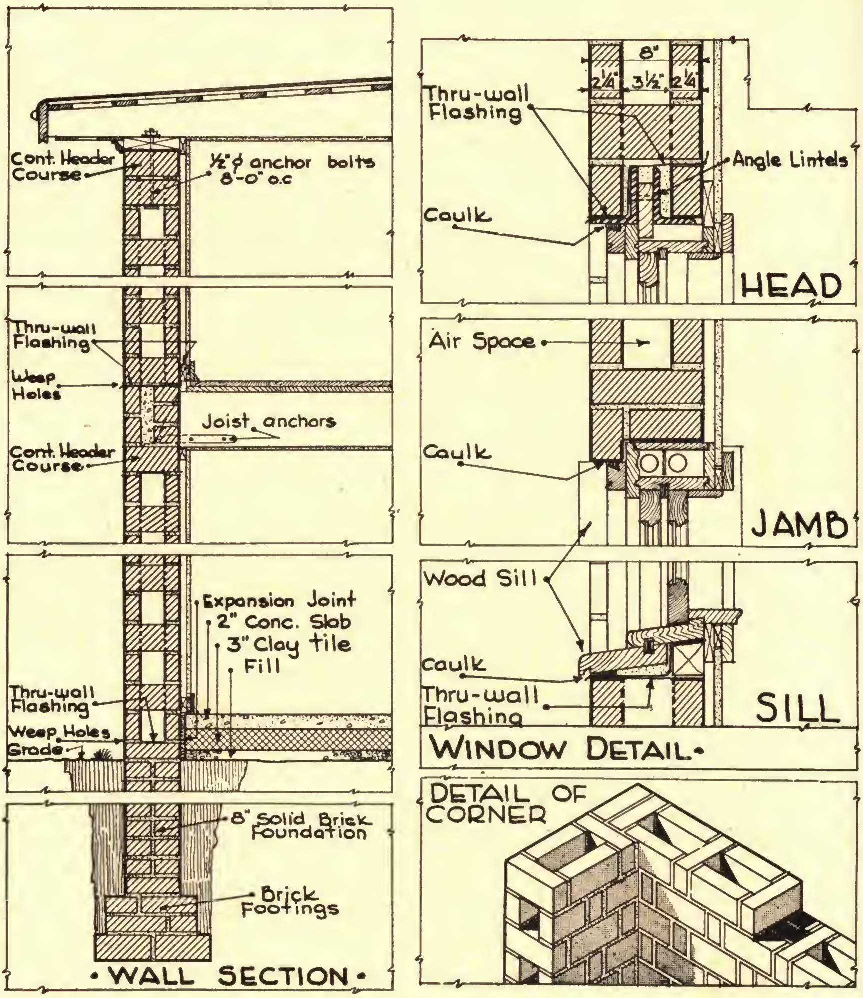


FIG. 8-8

Typical section and details of 8-in. all-rolok wall in Flemish bond

806. ECONOMY WALLS

The Economy Wall is a 4-in. wall built of brick laid flat and stiffened at suitable intervals by pilasters projecting 4 in. from the wall. It is designed primarily for one-story cottages, garages, filling stations or similar buildings, but may also be used for two-story buildings where building codes permit. The exterior appearance of the wall is practically the same as that of any brick wall laid in common bond, except for the headers at the pilaster points. Other bond patterns may be used by simply spacing the pilasters at the proper distances to fit the location of headers in the pattern.

Pilaster spacing may vary from two stretchers between 4-in. wide pilasters to four and one-half stretchers between 8-in. wide pilasters. Corners and jambs of openings must always be formed with pilasters preferably 8 in.

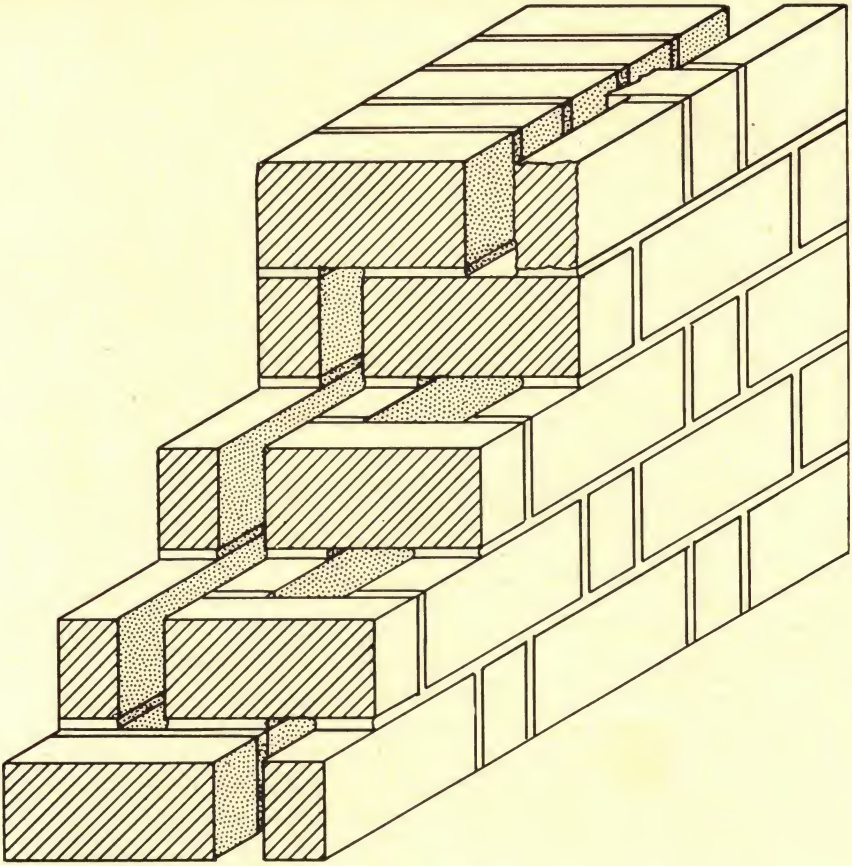


FIG. 8-9

12-in. all-rolok wall in Flemish bond

wide. Pilasters may also be built on both sides of the wall, forming a pier and panel wall, and if, for design purposes, the piers are spaced at wide intervals, the panels may be stiffened at intermediate points with pilasters on the back of the wall.

For greater lateral strength and permitting wider spacing of pilasters, these walls may be reinforced by embedding continuous ¼-in. bars or 3-in. strips of expanded metal or welded mesh in every fourth or fifth horizontal mortar bed. Vertical reinforcing bars may also be placed in pilasters that are at least 8 in. sq. Courses should be carefully laid out in advance to determine the proper location of pilasters with relation to headers, corners and openings. The brick should be laid on smooth mortar beds, not furrowed, and all vertical joints completely filled to produce maximum strength and resistance to moisture penetration. As a further precaution against dampness, the backs of the panels may be parged (plastered) which also reduces the heat transmission through the wall.

Supports for floor or roof members, sills and lintels are built 8 in. thick with bars in the bottom mortar bed to form R-B-M beams supported on the

pilasters. The correct depths and bar sizes should be determined for the loads and spans in accordance with a structural design. Construction of these members requires only the erection of temporary soffit forms properly shored in place.

A flashing strip should be provided above openings if the wall is only 4 in. thick at this location. The purpose is to divert any condensation which might accumulate and keep it from reaching the frame. This strip should extend at least 6 in. beyond the jamb pilasters and have the upper edge bent out at least ½ in. from the brick or mortar.

Interior finish may be applied to economy walls in several ways. Wood furring may be erected, 1 in. thick where the strips occur over pilasters and 2 in. thick elsewhere, to receive lath and plaster or wall board. Expanded metal or woven wire lath may be applied and fastened directly to the pilasters

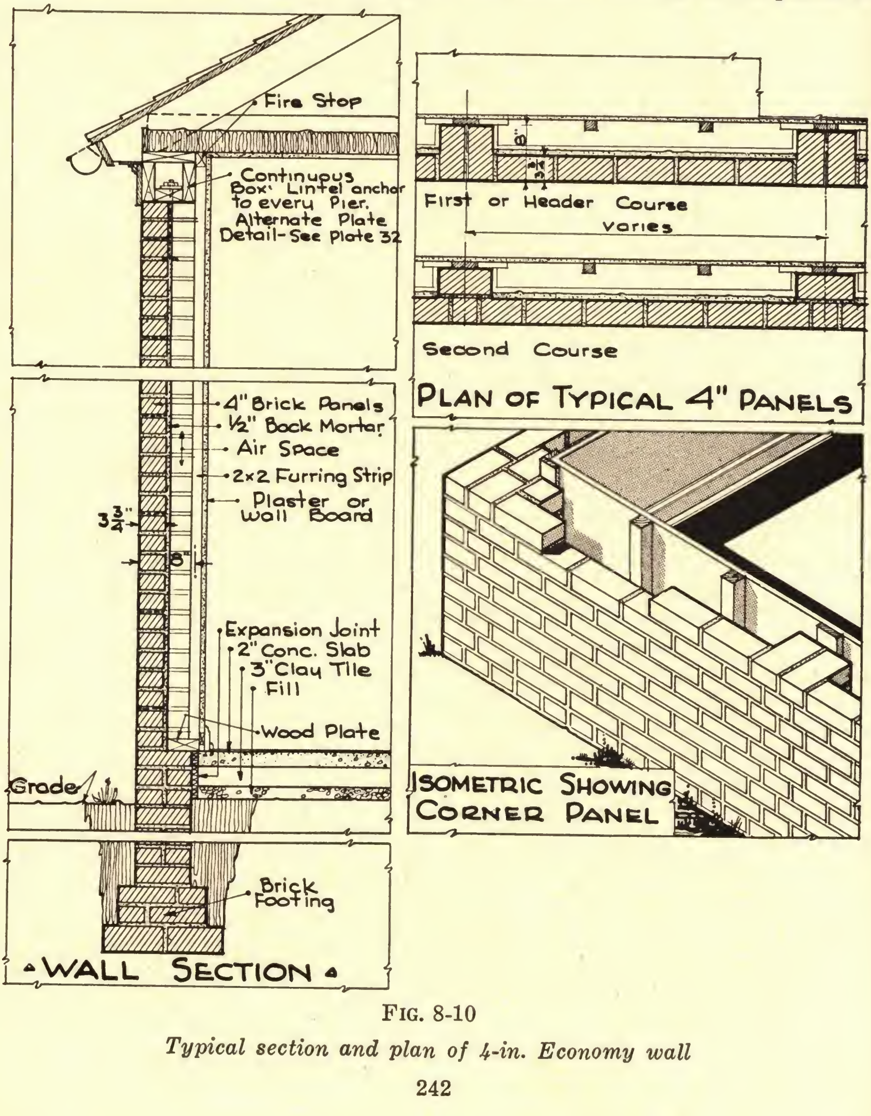


FIG. 8-10

Typical section and plan of 4-in. Economy wall

or to metal furring strips on the pilasters, held by means of wire ties built into the mortar beds. The latter is preferable since it eliminates combustible materials entirely from the wall construction.

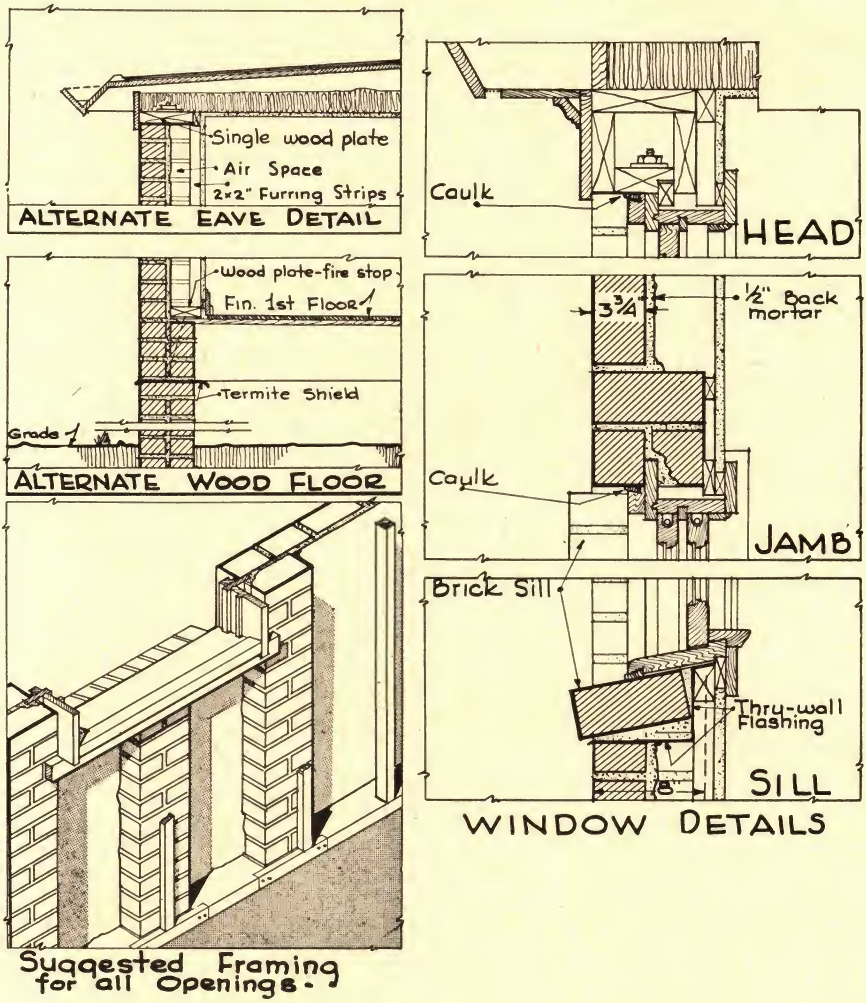


FIG. 8-11

Typical wall section and details of 4-in. Economy wall

Fig. 8-10 and 8-11 show wall sections and details of a typical 4-in. economy wall.

807. SPECIAL TYPES OF BRICK WALLS

Various special shapes have been developed for use in the construction of hollow walls with brick headers. The purpose of these shapes in most types is to eliminate the use of through headers. Outstanding of the types of construction using special shapes are the Farren-Wall and Cain Air-flow Wall.

808. BRICK VENEER

The use of brick veneer as a facing material only, without utilizing its load-bearing properties, has found applications principally to dwellings in many parts of the country. Such veneering is usually applied over wood framing and sheathing of both old and new houses.

In appearance, a brick veneer wall may have most any distinctive character and colorful beauty. The brick may be laid in any bond or pattern formed by the use of half brick as headers.

Structural stability is obtained by (1) sufficiently strong and well braced frame backing; (2) ample support, and anchorage of the veneer to the backing and (3) good construction of the brickwork.

Veneered walls resist exterior fire exposures better than frame, but have about the same internal resistance.

In new construction, the foundation walls should extend 5 in. outside the face of the wood sheathing to receive the brick veneer. On old buildings the veneer should be started on the projecting portion of the footing or on a steel shelf angle bolted to the foundation wall, but never on an angle fastened to wood sill or framing members.

The wood walls should be covered with waterproof building paper and the veneer anchored in place with a non-corrodible metal tie for each 2 sq. ft., spaced not more than 24 in. apart either vertically or horizontally.

Steel angles are used over openings and, where the veneer extends above roofs, supporting angles should be firmly lag-bolted to the framing.

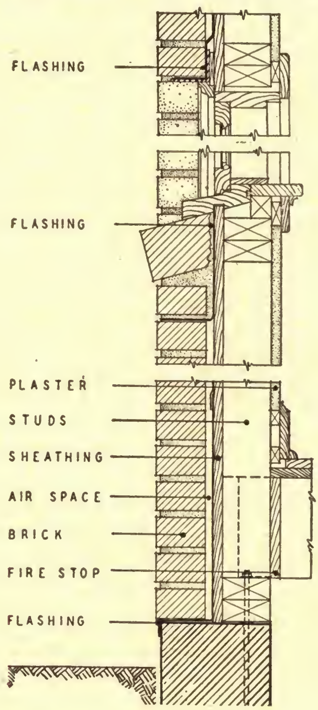


FIG. 8-12

Typical details of brick veneer on new frame construction

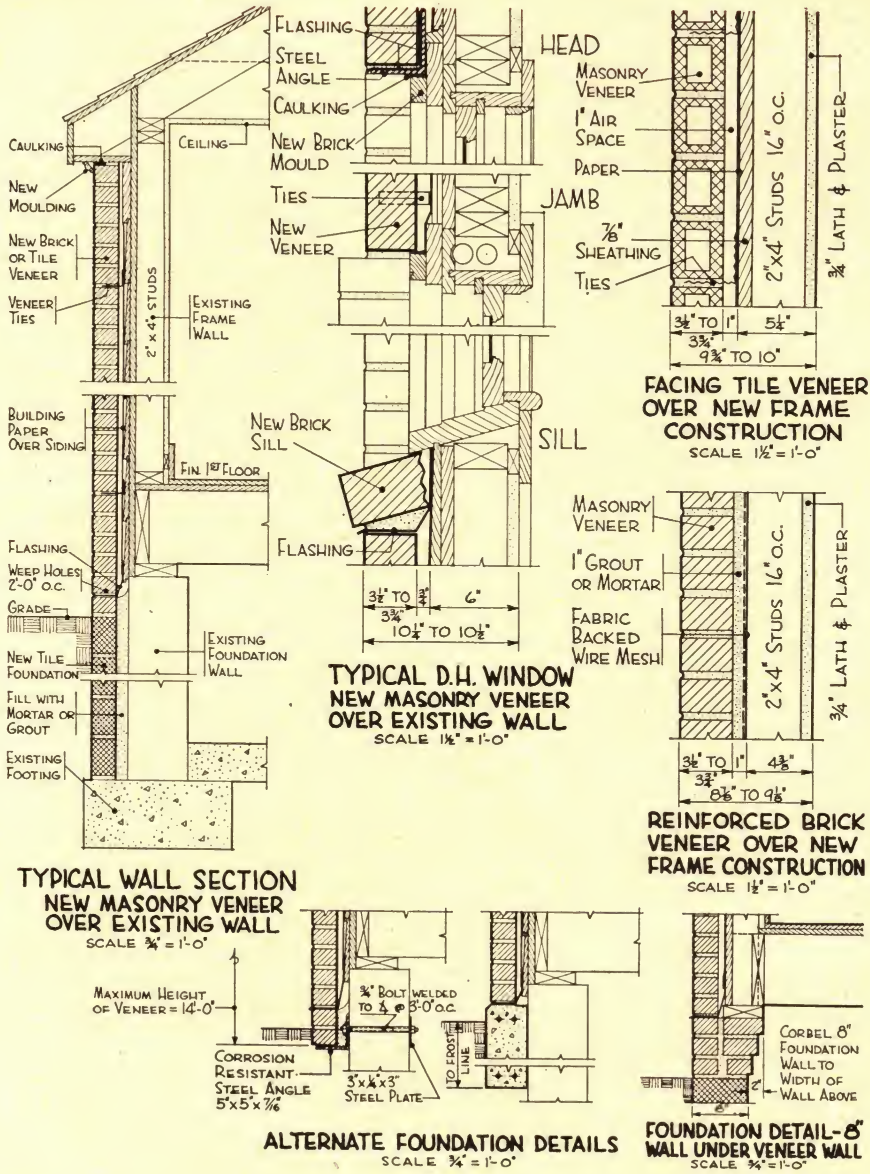


FIG. 8-13

Typical details of brick and tile veneer on both old and new frame construction

Reinforced brick veneer is formed by applying to the sheathing a fibrous backed welded wire mesh of heavy gauge. The space behind the brick is then slushed full of mortar and the wall ties are attached to the fabric.

Fig. 8-12 and 8-13 show typical details of brick veneer on new and old frame construction, respectively.

809. CAVITY WALLS

The cavity wall consists of two sections or wythes of masonry separated by a continuous air space, not less than 2 in. wide. The two wythes are composed of either structural clay tile or brick, or a combination of both. Metal ties are used to bond the two wythes.

Relatively high strength mortars should be used in the construction of cavity walls as an assurance of adequate lateral strength. A mortar consisting of 1 part cement, ¼ part lime putty to 3 parts sand, by volume, or a mortar of equal strength is recommended.

A metal wall tie, consisting of a steel rod 3/16 in. in diameter, or a metal tie of equivalent stiffness coated with a non-corroding metal or other approved protective coating should be used for each 3 sq. ft. of wall surface. Various types of metal ties are available designed with a drip between the two wythes to prevent the passage of moisture across the tie; however, experience with the 3/16-in. round ties recommended above indicates that for this type of tie the drip is unnecessary. Ties should be placed approximately within 8 in. of all openings and immediately below the level of bearing of the floor joists. The cavity should be kept clear of mortar droppings.

The bottom of the cavity should be located above ground level, and the cavity should be drained by weep holes in the vertical joints of the bottom course of the outer wythe. The holes, spaced 2 ft. apart, may be easily formed by leaving an open vertical joint between brick in the bottom course, or by setting a short length of rubber hose in the mortar joint, which can be removed after the mortar has set.

Flashing should be installed over all openings unprotected by roof or hood structures above to deflect moisture outward through the outer wythe. The flashing should extend 6 in. beyond the jamb on each side of the opening. Where the cavity extends several inches below the lowest bearing level of the ground floor, and the bottom of the cavity is above ground level, no flashing need be provided at the bottom of the cavity, but a damp course should be placed in both the inner and outer wythe one course above the bottom of the cavity and below the bottom of the first floor joist. When flashing is used at the bottom of the cavity, it should be continuous, as indicated in Fig. 8-14.

(a) Wall-Bearing Cavity Walls. Tests on cavity walls, sponsored by the Structural Clay Products Institute and conducted at the National Bureau of Standards, are reported in Building Materials and Structures Report BMS24. The results of these tests indicate that cavity walls consisting of two 4-in. wythes of masonry have ample strength for the normal loading conditions of residential and office classes of occupancy and for heights up to two stories.

Fig. 8-14 and 8-15 show typical wall-bearing cavity wall construction for a two-story residence. Here shown with wood floors and roof, cavity bearing walls are equally well adapted to use with steel or masonry floor and roof framing.

For higher structures and for structures designed for heavier loadings than residential or office classes of occupancy, it may be necessary to increase the thickness of the inner wythe of masonry. The interior face of the masonry may be plastered direct or it may be furred, lathed and plastered.

Plaster on the interior face of the wall may be eliminated when the inner wythe is built of structural facing units or of other masonry suitable for

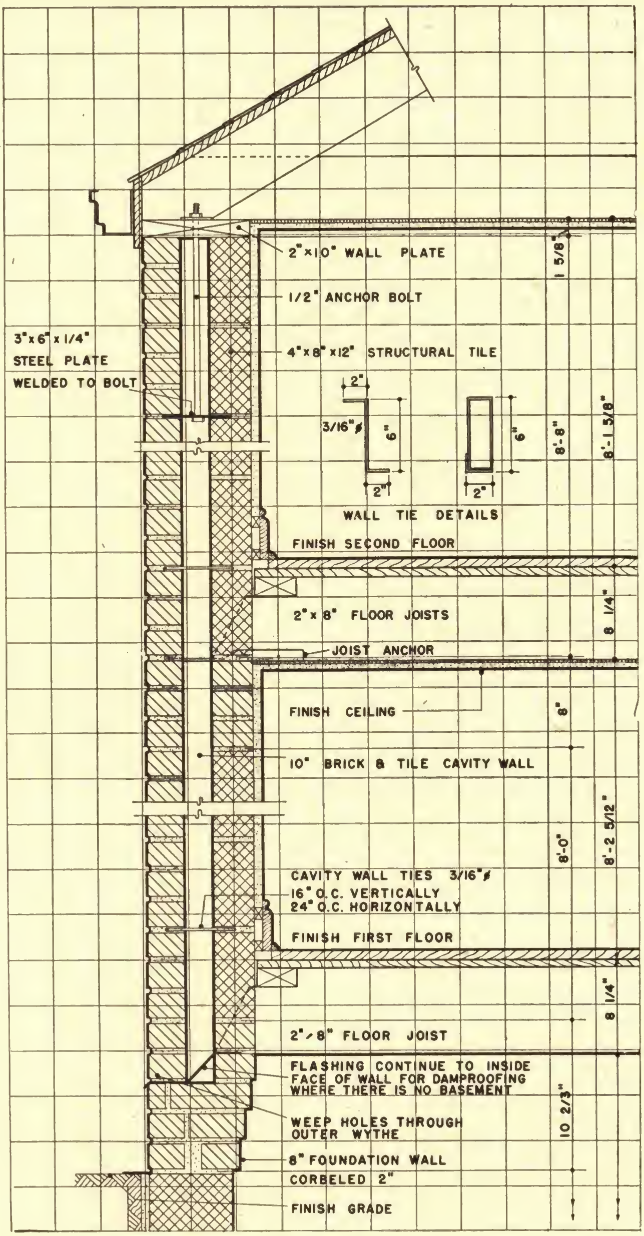


Fig. 8-14

Typical section of 10-in. wall-bearing cavity wall construction

exposed interior use. Cavity walls of this type, with attractive interior finish walls of masonry, have been used both for public housing developments and for private residences as well as for industrial and commercial structures.

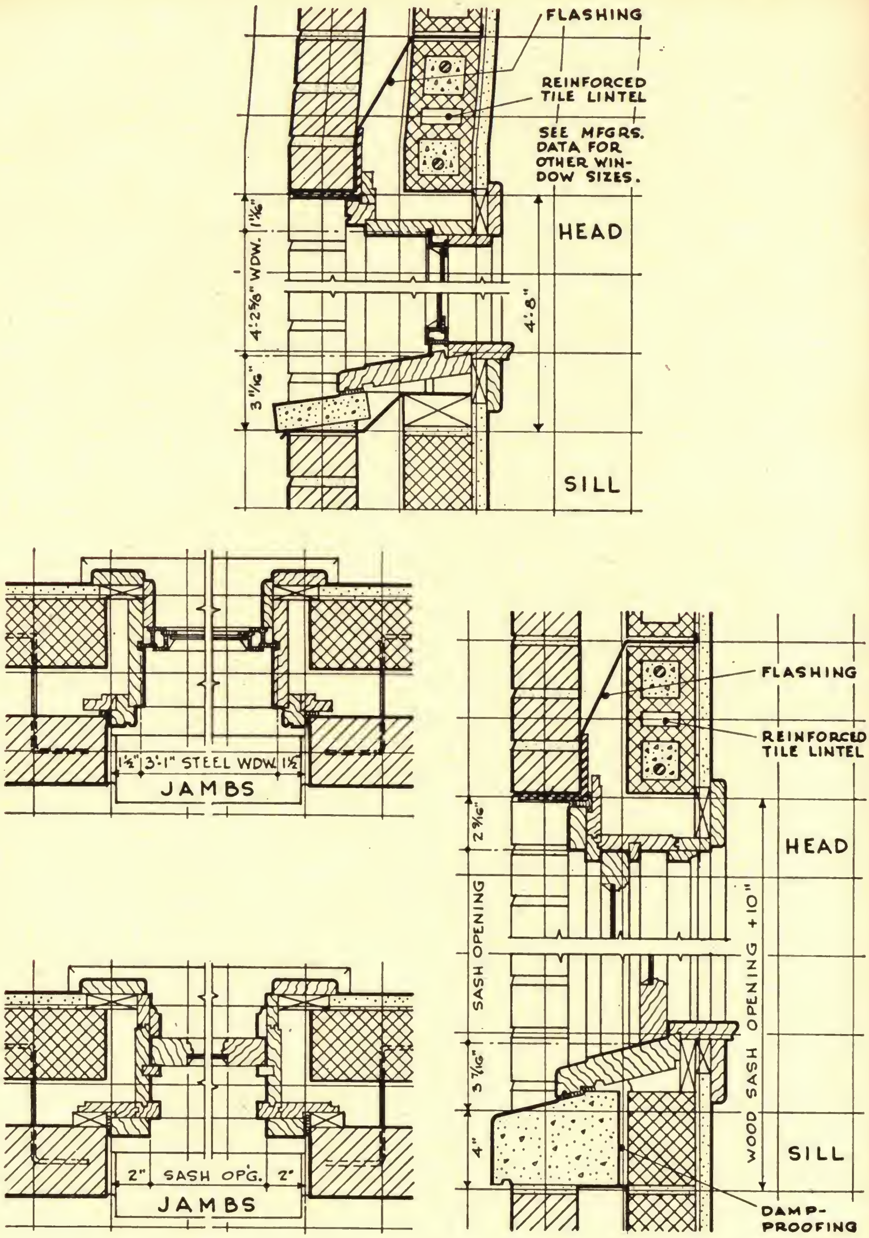


FIG. 8-15

Typical window installation details in wall-bearing cavity wall construction

Interior masonry walls offer design possibilities in keeping with a current trend toward the decorative use of exposed structural materials.

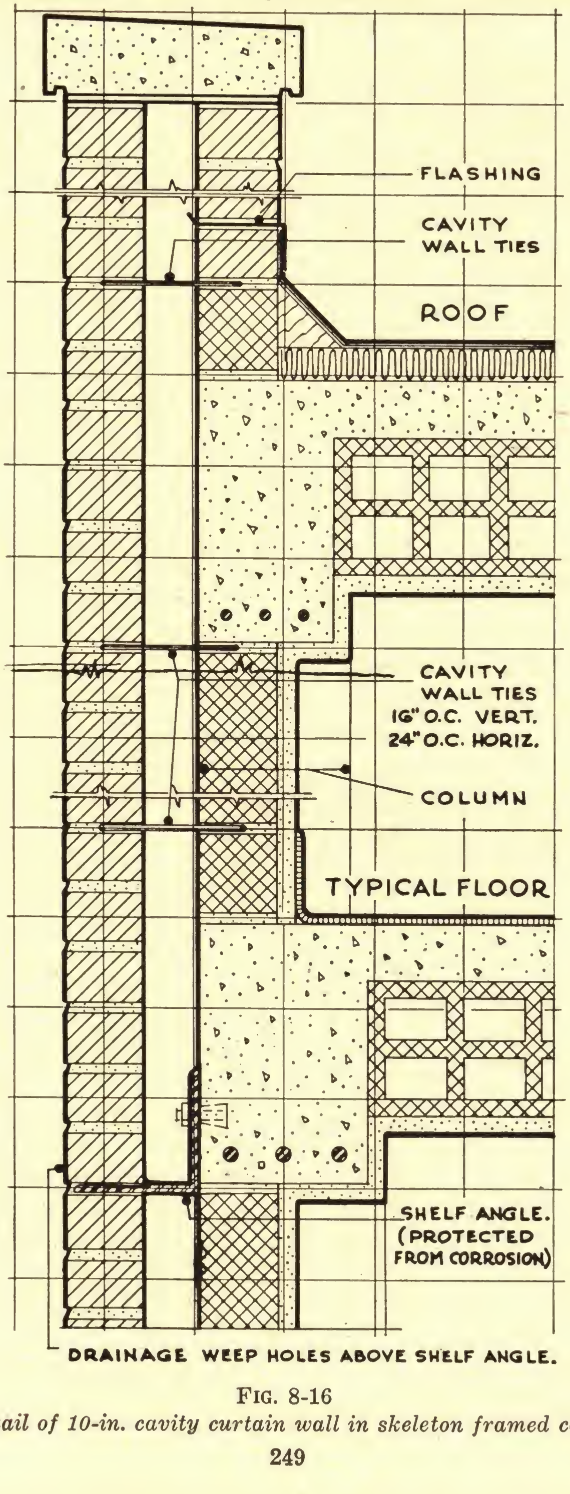


FIG. 8-16

Typical detail of 10-in. cavity curtain wall in skeleton framed construction

(b) Cavity Walls for Skeleton Framed Buildings. Many problems of curtain wall construction can best be solved through the use of masonry cavity walls as shown in Fig. 8-16.

(1) Moisture penetration cannot occur beyond the outer wythe of masonry in a properly constructed cavity wall.

(2) The cost of spandrel flashing is saved.

(3) Dampproofing the interior face of the wall is unnecessary. Plaster can be applied directly to the masonry wall.

(4) The overall heat transmission coefficient, U, of a 10-in. brick and tile cavity wall, plastered, is .30. Where a lower coefficient is desired the wall may be furred or otherwise insulated.

The wall section in Fig. 8-16 shows the most effective location of the curtain wall of cavity construction. The outer face of the inner masonry wythe is placed flush with the face of spandrel beams and columns, thereby providing a continuous air space between the frame and the outer wythe of masonry.

Where the outer wythe is supported on spandrel beams, galvanized shelf angles, flashed where end joints abut, may be used to provide structural support and cavity flashing in one member, thus eliminating the need for continuous strip flashing.

In lieu of galvanized angles, flashing may be installed over the top face of steel shelf angles. No additional cavity flashing over heads of openings is needed when spandrel shelf angles coincide with the heads of openings.

810. STRUCTURAL CLAY TILE WALLS

Partitions of non-load-bearing structural clay tile are available in various thicknesses from 3 to 12 in., usually in a 12x12-in. face dimension. In some cases 5- and 8-in. unit heights are used but these sizes are generally confined to partitions where the natural surface finish of the tile unit is exposed. Partitions may be constructed of a single unit or of two or more units in the total thickness. Thus, various combinations of sizes and surface finishes may be obtained in a single partition.

Load-bearing structural clay tile units may comprise the entire bearing wall or the backing for brick or other facing material up to 50 ft. in height. Load-bearing tile are also used in party walls and in such non-bearing walls as panel, curtain and enclosure walls. The surfaces of these units may be suitable for the application of plaster or stucco, or they may have an exposed wall finish with the units smooth, combed or roughened as desired.

A great variety of structural clay tile shapes and designs are produced throughout the United States, however not all types are generally available in any single locality. The designer and builder can readily ascertain the prevailing standard sizes and shapes in a particular area and will find it advantageous to plan and estimate accordingly. When necessary, manufacturers can provide the required shapes and sizes to meet practically any construction problem, but it is readily understood that a design which utilizes the greatest number of standard units with a minimum of cutting and special shapes will provide the maximum economy.

Fundamentally, there are only two general types of structural clay tile; namely, end-construction tile which are laid with the cells vertical, and side-construction tile which are laid with the cells horizontal. Typical wall sections for various thicknesses of single, multiple, composite and cavity walls are illustrated in Fig. 8-17 to 8-24, inclusive.

811. TILE PARTITIONS

(a) Single-unit Construction—4- to 12-in. Thicknesses. In addition to their fire-resistive qualities, non-load-bearing partitions of structural clay tile are light, strong, durable, easily built by bricklayers, and resist the passage of both heat and sound. Partition tile, unless otherwise specified, are furnished with a plaster-base finish which may be smooth, scored, combed or roughened. When the exposed-wall finish is desired, it may be smooth (unscored), combed or roughened in accordance with the manufacturer's standard. When a certain standard finish is preferred, it should be so stated and described in the purchase specification. The desired finish may be specified on one or both faces and at least one end must be similarly finished. Frequently the exposed-wall finish may be desired on one surface while the opposite surface will require a plaster base finish.

It is not generally practicable to use 2-in. tile for partitions, except for closets, shafts, etc., provided they do not exceed a height of 9 ft. with an unsupported length of 6 ft. Partitions of 3-in. thickness can be safely used up to 12 ft. in height and corresponding increases in height may be obtained for additional thicknesses as shown in Fig. 8-17.

Partitions should be bonded at intersections and properly anchored to door bucks and masonry walls. In plastered construction, wood or steel channel bucks at door openings should be approximately 1½ in. wider than the thickness of the tile to act as grounds for the plaster.

(b) Multiple-unit Construction. Where 6-in. to 12-in. wall thicknesses are desired, and particularly for exposed finishes where both sides must be laid up true and accurate, multiple-unit partitions are used as shown in Fig. 8-18. They may consist of two separate wythes, free-standing or tied together with metal ties as shown in detail (b), or bonded mechanically in alternate courses, by overlapping the subjacent units, as shown in details (c) to (f).

Details (d) and (e) show examples of partition walls, where the 6-in. bonding units are at least 50 per cent greater in thickness than the units below. In this case, the vertical interval between bonding units should not exceed 17 in. Thus, with the 12-in. heights shown, alternate bonding courses are required; however, with 8-in. height units, the bonders may be placed every third course; or every fourth course with 5-in height units.

Where the units overlap at least 3¾ in. as shown in detail (f), the maximum vertical bonding interval may be increased to 34 in. Bond units may therefore be placed every third course for 12-in. height units and spaced correspondingly for units of lesser height.

These bonding intervals apply to exterior load-bearing walls of hollow structural clay tile units; also in composite walls where the hollow clay tile units are used for backing brick and stone. They also apply where maximum wall heights are desired as permitted by the combined thickness. For lesser heights the partitions may be veneered the entire height with thinner tile on one or both sides, however the height limitations will then be determined by the single thickness of the inner core wall.

Double walls of structural clay tile, as shown in detail (a) Fig. 8-18, are used extensively in housing projects, apartments, hospitals, lockers and shower rooms and also fireproof dwellings to provide a space for soil pipes and other utilities. These walls are usually constructed as shown with a 4-in. cavity and bonded with a through-masonry unit every 10 sq. ft. of wall

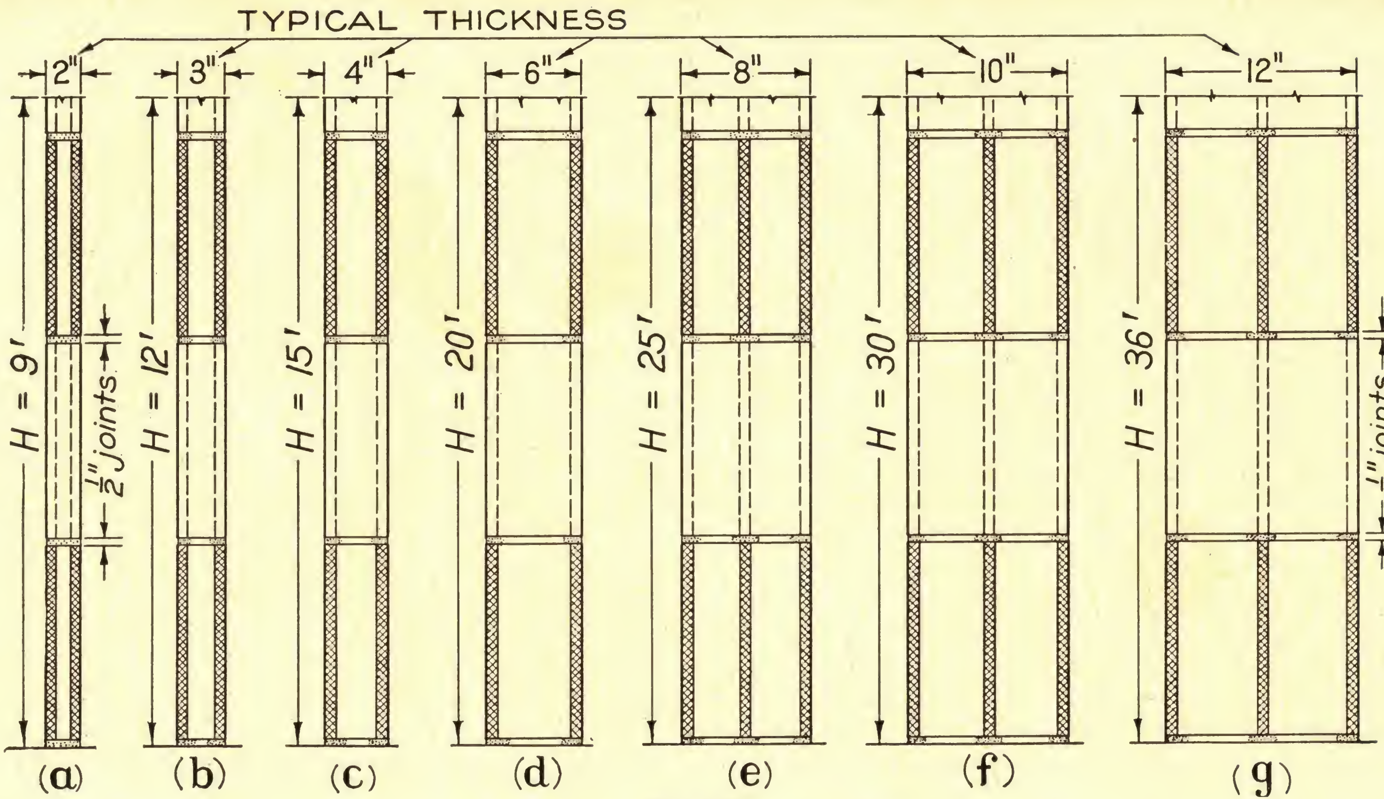


FIG. 8-17

Single-unit tile partition wall sections and maximum allowable heights "H"—vertical cell construction shown.

Note: (These units also laid with cells horizontal)

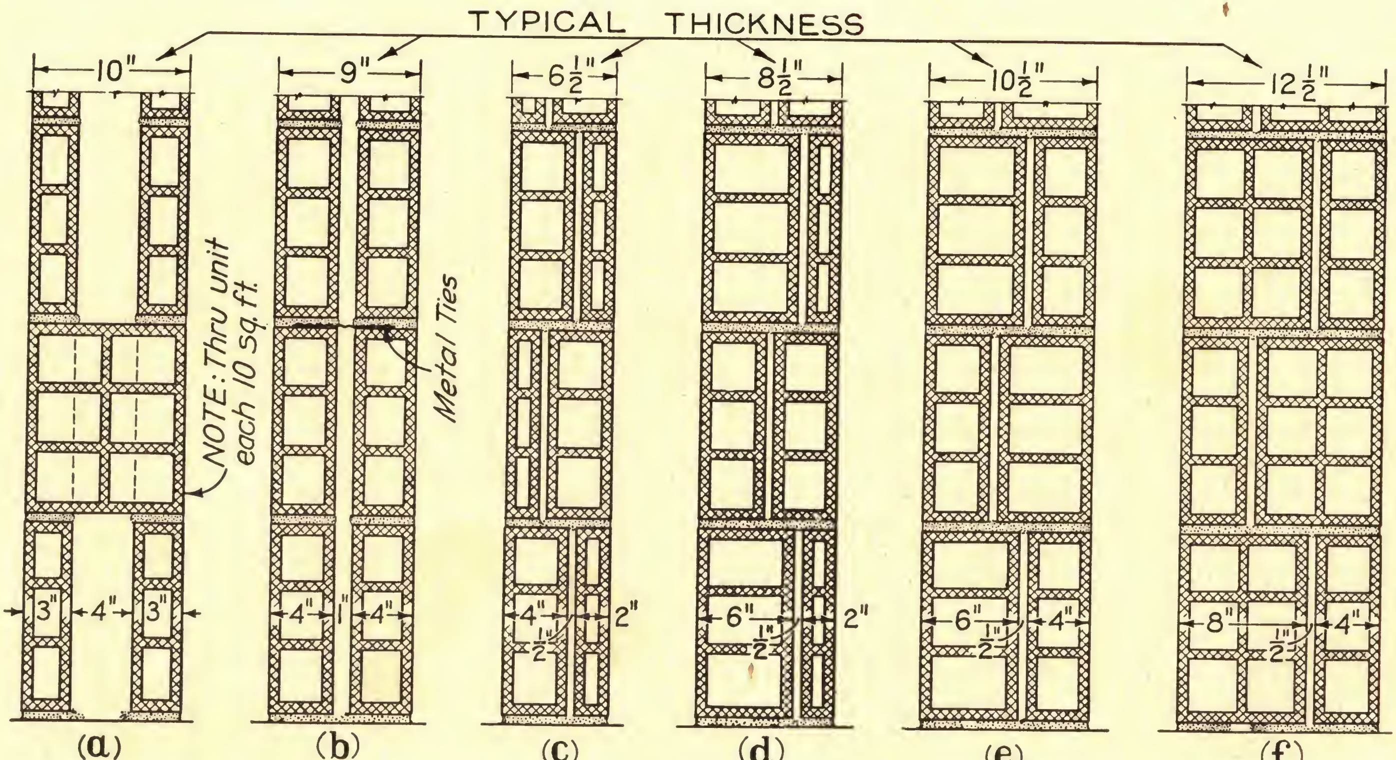


FIG. 8-18

Typical multiple-unit partition wall sections—horizontal cell construction shown

Note: (These units also laid with cells vertical)

area to provide rigidity and stability for the attachment of plumbing fixtures or other equipment.

812. SINGLE UNIT TILE WALLS

(a) Eight-inch Thickness. For load-bearing exterior and interior walls, a commonly used thickness of structural clay tile is 8 in. For this reason, single 8-in. thickness units are generally available in all the standard heights from 4 to 12 in. in smooth, scored and textured finishes in all the colors and shade ranges ordinarily associated only with facing brick.

Details (a) to (f), in Fig. 8-19, show both the former conventional (typical) heights of structural clay tile, as produced to be laid with any joint thickness "j", desired or specified, and the corresponding modular heights. Ordinarily the preferred joints are ¼ in. for glazed tile, ⅜ in. for unglazed facing tile and ½ in. for structural clay tile. On many jobs, however, the designer departed from these standards as a matter of preference or perhaps necessity to meet certain openings or floor and ceiling height requirements. With modular masonry units, the actual heights will be produced as shown, so that the unit plus the thickness of one mortar joint, or a combination of two or three units plus the joints, will be a single or a low multiple of 4 in. This will permit the coordination of structural clay tile units with other building materials designed in accordance with this system.

(b) Six-, Ten-, and Twelve-inch Unit Thicknesses. In the warmer sections of the country, the use of 6-in. thickness structural clay tile walls is rapidly increasing for low and some moderate priced dwellings, storage buildings, garages, etc. For minimum construction, ordinary load-bearing units are used without any interior finish, except paint in some cases. In localities where high humidity conditions are not prevalent, dwelling walls may be finished on the interior with a direct application of plaster. In general, however, it is advisable to attach wood or metal furring strips directly to the masonry wall to provide an air space between the wall and metal lath, plaster board or rigid insulation and plaster. When so constructed, these 6-in. walls are also recommended for one-story single-family dwellings in the colder localities. If desired, "bat" type mineral wool, glass, or fiber insulation may be placed in the space between the wall and plaster to obtain any required insulating factor. Maximum allowable height for 6-in. masonry walls in one-story dwellings and private garages is 9 ft., however, when gable construction is used, an additional 6 ft. is permitted to the peak of the gable.

As shown in Fig. 8-20, details (a) to (d), the present conventional popular heights and corresponding modular sizes are included for various 6-in. walls. Units shown in details (a) and (b) are generally used for exposed masonry, while the larger units shown in details (c) and (d) are often painted or stuccoed.

Details (e) and (f), Fig. 8-20, show 10- and 12-in. units in the most common conventional heights and corresponding modular sizes. In some localities these thicknesses are also available in nominal 5- and 8-in. heights.

The thicknesses shown may vary as much as ¼ in. from the manufacturer's designated dimension. It has been common practice to produce structural grade building tile approximately ¼ in. under the nearest full-inch dimension, however, the pre-modular facing tile are frequently the full thickenss or only ⅛ in. less. The nominal modular thicknesses for load-bearing tile will continue

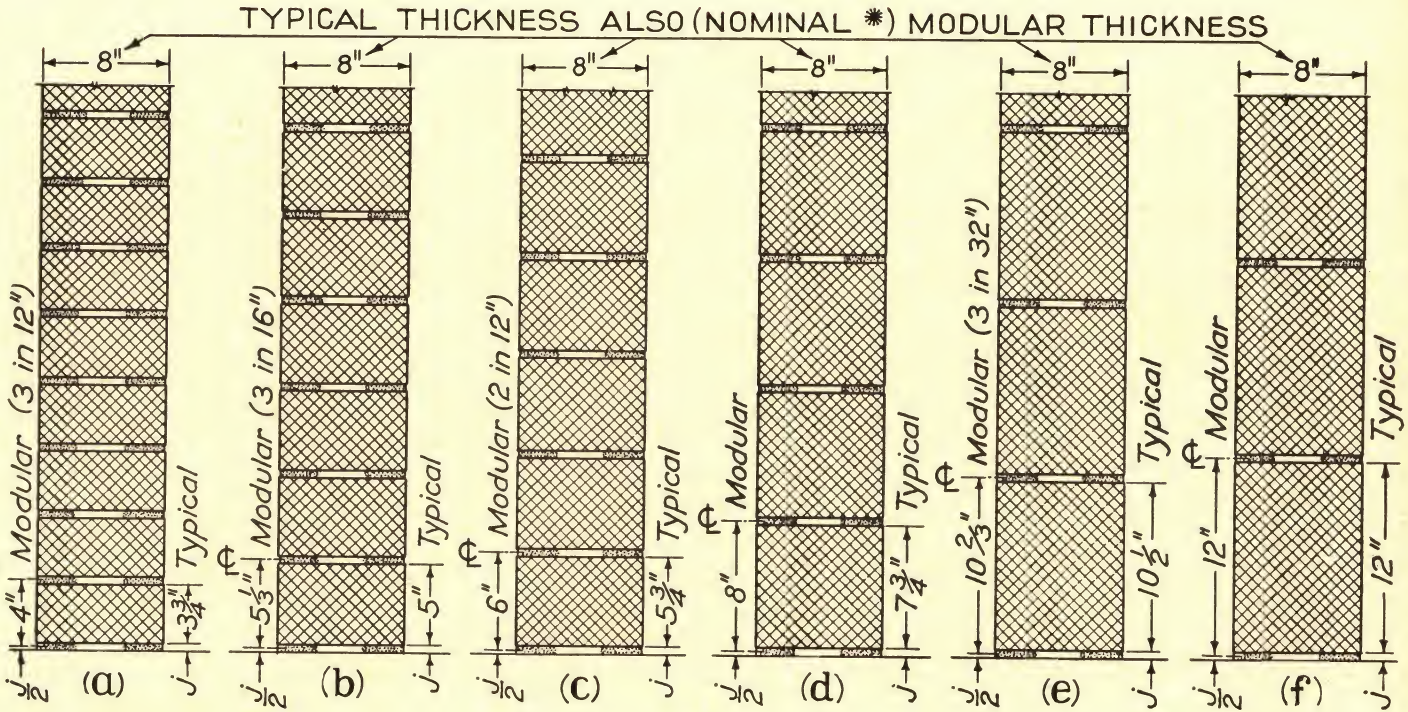


FIG. 8-19

Single-unit tile wall sections—(8-in. thickness)

*Note: *(Nominal modular size includes thickness of mortar joint (j) in unit height, length, and depth)*

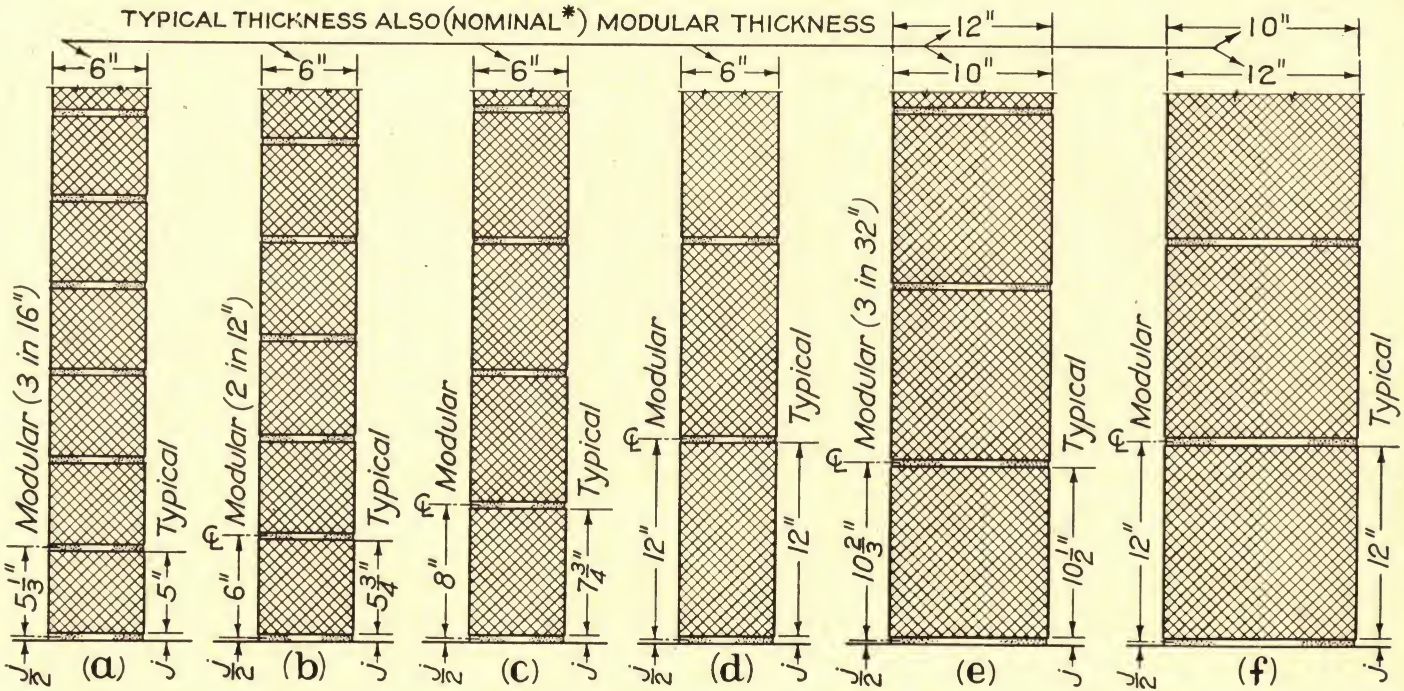


FIG. 8-20

Single-unit tile wall sections—(6-in., 10-in., and 12-in. thicknesses)

*Note: *(Nominal modular size includes thickness of mortar joint (j) in unit height, length, and depth)*

to be used in specifications, descriptions and small scale plan designations. However, the nominal modular thickness will include the thickness of one standard mortar joint (as determined by the grade or quality of the material) in each of the three dimensions—length, height, and unit thickness.

813. MULTIPLE UNIT TILE WALLS

(a) Six-, and Eight-inch Thicknesses. Fig. 8-21 shows three different unit combinations or sectional bonding patterns for both 6- and 8-in. tile walls. Various additional combinations may be made by the use of standard shapes and sizes if bonded in accordance with the requirements listed at the end of this section.

In detail (a) for example, two similar courses are shown in one position, followed by two courses of identical units in the reversed position. Since the height limitation of bonding courses for the units shown is 17 in., only one reversed course would be required in every fourth course. Ordinarily, this wall may be constructed by reversing the units in alternate courses.

Typical veneer construction is shown in detail (b). As illustrated, this wall would not be considered load-bearing since the effective wall thickness would be only 4 in. The minimum structural tile wall thickness for bearing construction is 6 in., and therefore, an overall nominal thickness of 8 in. would be required for this detail.

In detail (c), typical 12-in. height units are shown consisting of nominal 2- and 4-in. thick units reversed in position in alternate courses to form a 6-in. multiple-unit wall. This is accepted as load-bearing construction when supported at right angles to the wall face by floors, walls or pilasters, etc., at intervals not exceeding 9 ft.

Recommended bonding arrangements for nominal 8-in. load-bearing walls are shown in details (d) and (e). Since the bonding units overlap the subjacent units at least 3¾ in., a maximum bond course interval of 34 in. would be permitted. Detail (e) meets this requirement with headers every fourth course, however, the maximum bond interval could be increased to every seventh course with the units shown, or every fifth course using typical 8-in. height units. It should be noted that the 8-in. through bonding units are not generally used when perfectly true and level exposed masonry surfaces are desired on both faces. In that event detail (d), or modifications thereof, should be used. Eight-inch walls are used in load-bearing construction for unsupported heights up to 12 ft. or greater, provided the maximum distance between other supports (walls, columns or pilasters) does not exceed that distance.

Detail (f), Fig. 8-21, illustrates a typical 8-in. non-load-bearing wall, constructed of two thicknesses or wythes of 4-in. units. Walls of this type may be bonded with metal ties similar to those used in faced wall construction as described in Section 814. Units must be so arranged, however, that common bed joints are provided through the wall at vertical intervals not exceeding 25 in. to permit placing the ties without off-setting. At least one metal tie is required for each 3 sq. ft. of wall surface.

(b) Ten- and Twelve-inch Thicknesses. Multiple-unit structural clay tile walls, 10 and 12 in. in thickness are frequently used for the construction of commercial and storage buildings, apartments, housing projects and for interior bearing and division walls as required by building code regulations and to resist the combined stresses due to live, dead and other loads for which the building is designed.

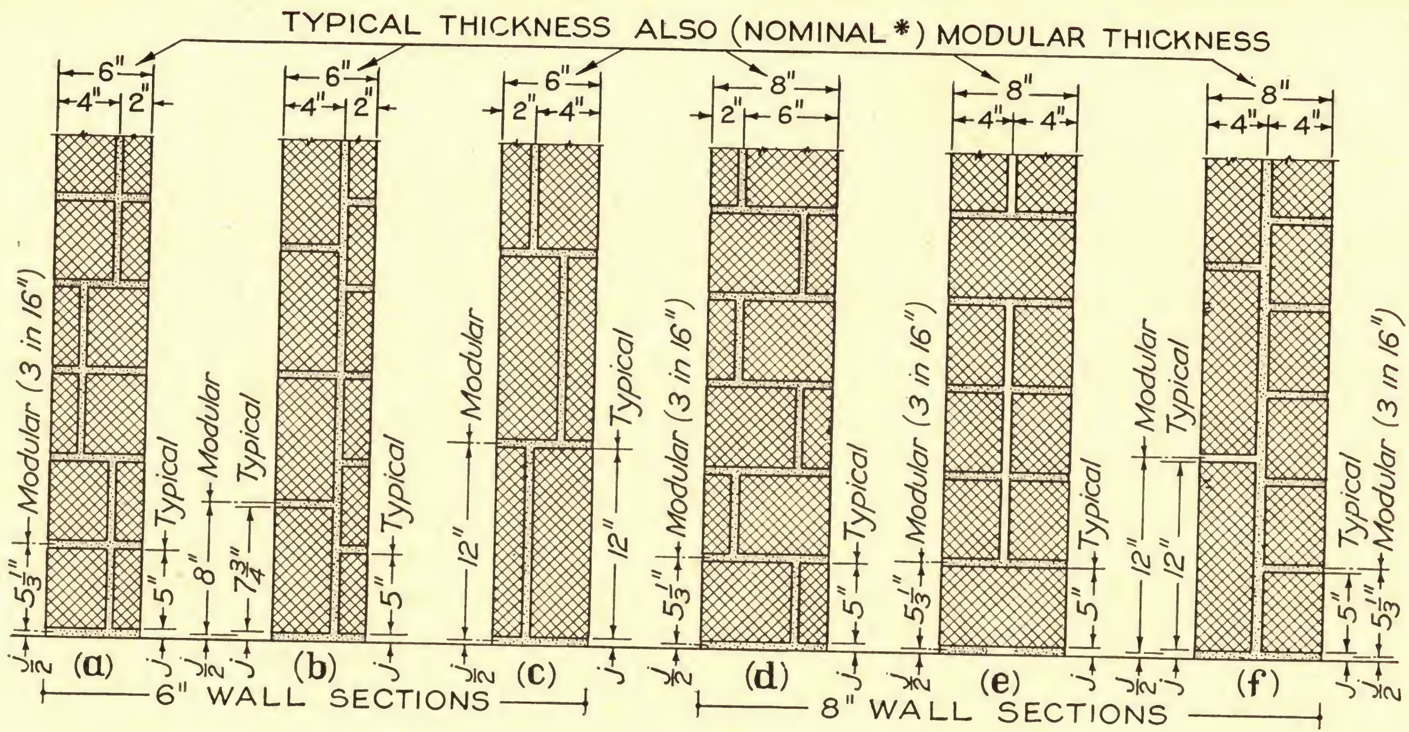


FIG. 8-21

Multiple unit tile wall sections—(6-in. and 8-in. thicknesses)

*Note: *(Nominal modular size includes thickness of mortar joint (j) in unit height, length, and depth)*

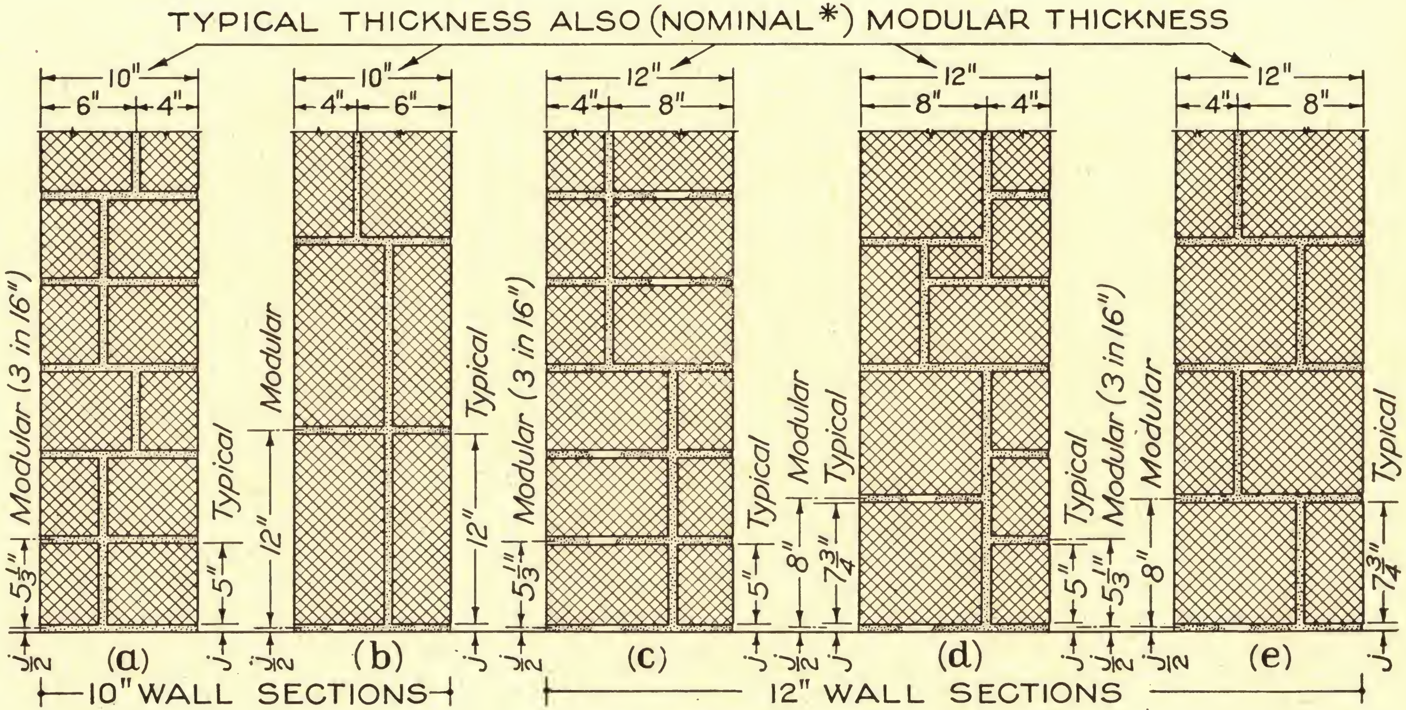


FIG. 8-22

Multiple unit tile wall sections—(10-in. and 12-in. thicknesses)

*Note: *(Nominal modular size includes thickness of mortar joint (j) in unit height, length, and depth)*

Units are generally available for stretcher and bonding courses for multiple unit walls of any total thickness, in 2-in. increments. Details (a) to (e), Fig. 8-22, show only a few typical patterns. Many additional combinations may be made with standard load-bearing units provided the wall design meets the following bond requirements:

(1) Structural clay tile units shall have full mortar coverage of the face shells in both the horizontal and vertical joints.

(2) Where two or more hollow structural tile units are used to make up the thickness of a wall, the stretcher courses shall be bonded at vertical intervals not exceeding 34 in. by lapping at least 3¾ in. over the unit below, or by lapping with units at least 50 per cent greater in thickness than the units below at vertical intervals not exceeding 17 in.

(3) Where walls of structural tile units are decreased in thickness, a course of solid masonry (25 per cent maximum voids) shall be interposed between the wall below and the thinner wall above. (Typical hollow structural tile units may also be used provided the cells are filled with cement-grout at the plant or job-site and properly cured before placing in position.

814. FACED OR COMPOSITE WALLS

(a) Eight- and Ten-inch Thicknesses. Various typical bonding methods and sizes of structural tile units used as backing for exposed brick and facing tile are shown in Fig. 8-23. As illustrated, 8-in. composite load-bearing masonry walls, details (a), (c), (d) and (e), are generally bonded by means of through-wall header units at intervals not exceeding 20 in. either vertically or horizontally with at least one full brick header in each 1.5 sq. ft. of wall surface. When brick units are used as facing, this requirement is ordinarily obtained by the use of continuous headers in each seventh course or Flemish-bond headers (alternating header and stretcher units) in each sixth course. Structural hollow tile facing units are bonded as described for multiple-unit walls in Section 813. Where desired, a combination of the nominal 4-in. thickness, 5- and 8-in. height backing units in alternate courses is ordinarily used for sixth-course brick header construction in 8-in. composite walls. Additional standard sizes are also available in certain localities, or furnished on special order for other required bonding intervals.

The use of non-corrodible metal ties for veneered masonry walls is illustrated in detail (b). Spacing of metal ties for this construction should not exceed 24 in. either vertically or horizontally. Where the backing units are at least 6 in. in total nominal thickness the walls are load-bearing construction, except in cavity wall construction where the load-bearing wythes may be 4-in. nominal thickness. In no case shall the veneering be considered a part of the wall in computing the strength nor is it considered a part of the required thickness of bearing walls. In accordance with the recommendations of ASA Committee A41, as contained in the American Building Code Requirements for Masonry, A41.1—1944, veneering should not exceed 35 ft. in height above foundations or other approved support.

A common method of constructing 10-in. composite masonry walls is illustrated in detail (f). The rectangular backing unit may also be furnished in nominal 5-in. and 8-in. heights, also other special heights for header bonding units spaced at fourth to seventh course intervals. The L-shaped header units permit the use of full brick headers and prcvide an uninterrupted interior tile surface.

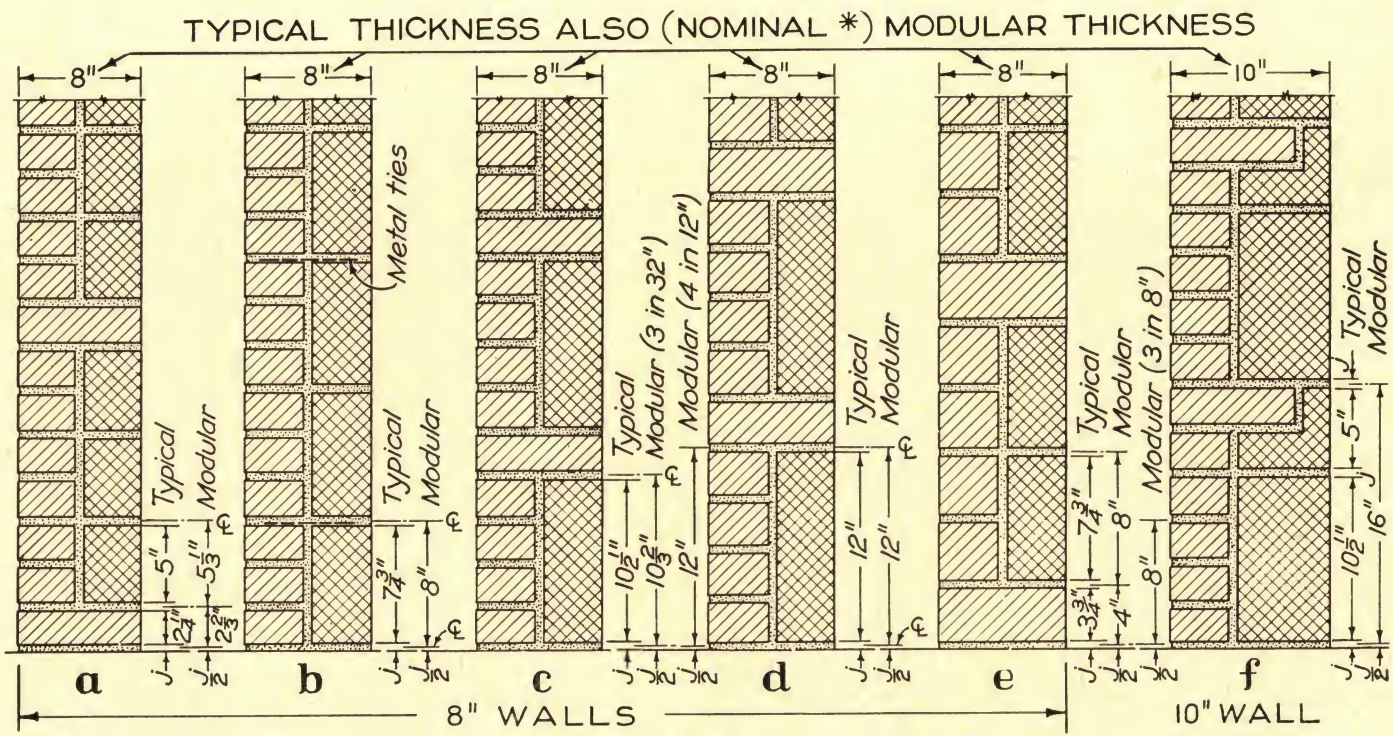


FIG. 8-23

Brick and tile composite wall sections—(8-in. and 10-in. thicknesses)

*Note: *(Nominal modular size includes thickness of mortar joint (j) in unit height, length, and depth)*

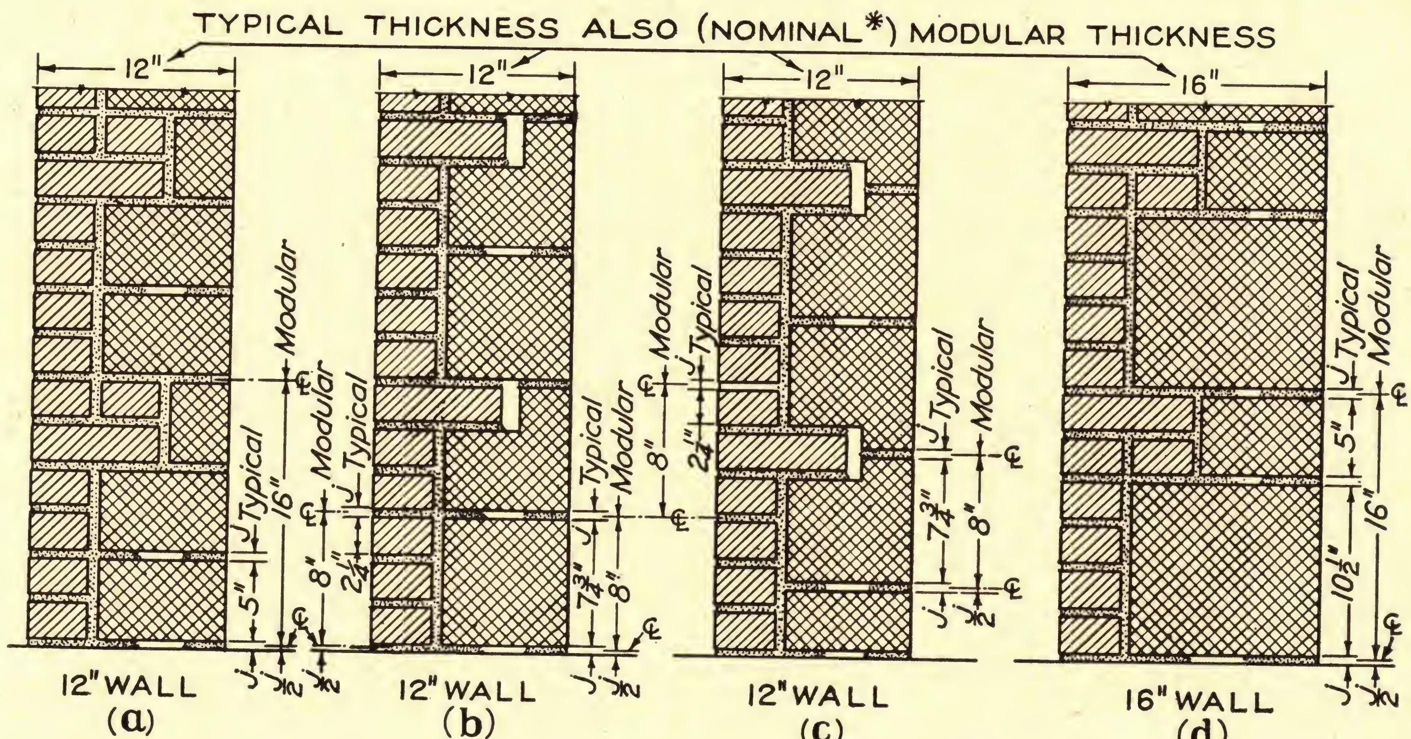


FIG. 8-24

Brick and tile composite wall sections—(12-in. and 16-in. thicknesses)

*Note: *(Nominal modular size includes thickness of mortar joint (j) in unit height, length, and depth)*

Other structural clay tile backing units for 10-in. composite walls, containing special hand grips and divided mortar joint features, including the single-unit reversible types, are available in many localities.

(b) Twelve and Sixteen-inch Thicknesses. With the exception of 8-in. masonry walls for residential construction, 12-in. brick and tile composite walls, as shown in Fig. 8-24, details (a) to (c), are the most widely used type of masonry wall construction. They are adaptable to practically all types of buildings, including schools, hospitals, office buildings, stores, apartments, multiple housing projects, factories, commercial building, etc.

Header bond requirements for brick and solid masonry units described above in part (a), are similar for all wall thicknesses. Various popular types of backing units are indicated in Fig. 8-24, as designed for use with sixth-course brick headers. Combinations of these units are also used for other header intervals.

In composite walls where more than two units are used through the wall thickness, the inner joints of header courses should be covered with another header course breaking joints with the subjacent course. When two or more units in the wall thickness consist of hollow structural building or facing tile, the header bond requirements should conform to those listed at the end of Section 813.

815. STRUCTURAL FACING TILE WALLS

(a) Typical Sizes. Structural clay facing tile are furnished in various face sizes from the single-brick equivalent to the nominal 8 x 16-in. face size.

The nominal 4-in. thickness, 2¼ x 8-in. face size and the standard modular 2 2/3 x 8-in. size are generally classified as "brick" as they are almost universally produced with the "net cross sectional area at least 75 per cent of the gross area, when measured in a plane parallel to the bearing surface of the unit."

Several larger sizes, up to and including units 4 in. high and 12 in. long, in the nominal 4-in. thickness, also receive the brick classification provided they conform to the above requirement for net area. Similar units greater than 4 in. in thickness, and comparable units with face dimensions exceeding 4 in. in height or 12 in. in length in all thicknesses, are classified as "solid masonry units."

In some localities, several types of vertical and horizontal cell single-brick face size units are furnished in an 8-in. nominal thickness for complete wall construction. These units, designed to resemble smooth or textured facing brick in appearance, provide increased insulation and economy in labor and material. These multiple unit sizes may be classified as "solid masonry units", provided the net cross sectional area is *at least* 75 per cent of the gross cross sectional area, including holes, recesses and re-entrant spaces, when measured in a plane parallel to the bearing surface of the unit.

Units in all thicknesses and face sizes are classified as "hollow structural tile" when the net cross sectional area in any plane parallel to the bearing surface is *less* than 75 per cent of its gross area measured in the same plane. This designation applies to structural building tile as well as structural facing tile.

Both "standard" and "special duty" structural facing tile are available in most localities. The latter are designed to have superior resistance to impact and moisture transmission and to support greater lateral and compressive loads than standard tile construction.

Supplementing the standard stretcher units, all manufacturers produce standard fittings to meet the requirements of practically all job conditions. These include half lengths, corners, and full and half jamb units. Corner and jamb blocks are frequently made from standard multi-cored universal cutting units, arranged with cores in 1-in. spacing to permit easy cutting by the mason as required.

Most of the high grade, light-burning fire clay facing tile units are furnished in the nominal 4-in. thickness and 8-in. and 12-in lengths. Thicker units in these grades are generally used for bonding purposes, while the soaps or nominal 2-in. thicknesses are used principally for lining or veneering. The soap or furring units are particularly adaptable for jobs located at great distances from the plant, where it is usually more economical to use local backing materials, rather than to utilize the facing tile in the full load-bearing capacity as a portion of the structural wall as ordinarily recommended.

The complete line of shapes and fittings in the high grade facing tile includes square, bullnose and coved corners, bullnose caps and cove base shapes, as required for the various thicknesses and job conditions.

It should be noted that not all face sizes are produced in the various surface finishes, colors and textures; however, the popular 5⅓ x 8-in. and 5⅓ x 12-in. modular sizes are almost universally available in the full range of colors and textures. The purchaser should determine the sizes and types most readily available or ordinarily transported into the locality by reference to manufacturers' catalogs.

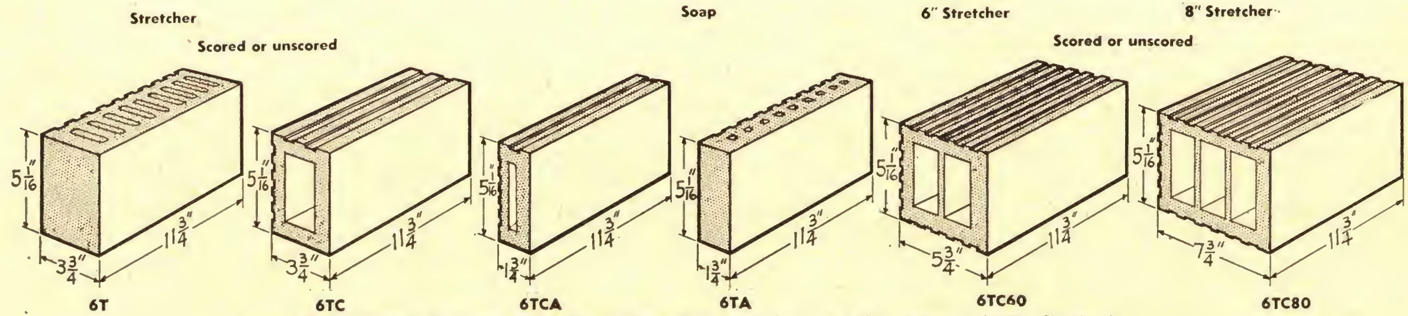
Structural facing tile produced by the members of the Facing Tile Institute include all of the varied sizes of stretchers and shapes, together with the required fittings, in ceramic, salt, and clear glazes or unglazed finish for every conceivable use involving facing tile. These units are now produced in modular sizes in accordance with the program of dimensional coordination for all basic building materials.

Space does not permit showing illustrations of the various sizes and shapes available; however, several of the typical basic stretcher units are shown in Fig. 8-25 and 8-26 for the nominal modular 5⅓ x 8-in., 4 x 12-in., 5⅓ x 12-in., and 8 x 16-in. face sizes. Both horizontal and vertical cored units are shown but in only one of many typical cell or core patterns. In general, the cellular designs in the horizontal type are quite similar; but the size, type and spacing of cores in the vertical cored units may vary considerably from one manufacturer's product to another. Stretcher units are furnished with either scored or smooth backs in the nominal 4-, 6-, and 8-in. thicknesses and also selected two-faced units in the 4-in. size. Soap units (nominal 2-in. bed) are usually furnished with scored backs only. These units are designed to be laid with ¼ in. mortar joints.

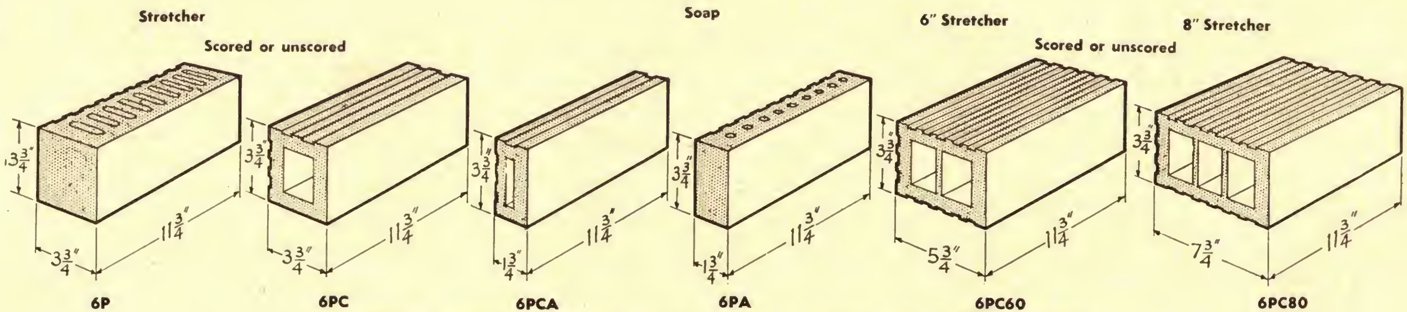
(b) Construction details. Typical partition and wall section details for high grade glazed and unglazed facing tile units, illustrating the various sizes and bonding methods, are shown in Fig. 8-27 to 8-32, inclusive.

816. CONSTRUCTION DETAILS

A few examples of the construction details involved with the use of structural clay building units are illustrated in Fig. 8-33 to 8-44, inclusive. Space will not permit describing or showing standard details for all sizes and types of units; however, this information is available from circulars and catalogs and may be obtained from the manufacturer or clay products dealer for the various standard and special types described in this chapter.

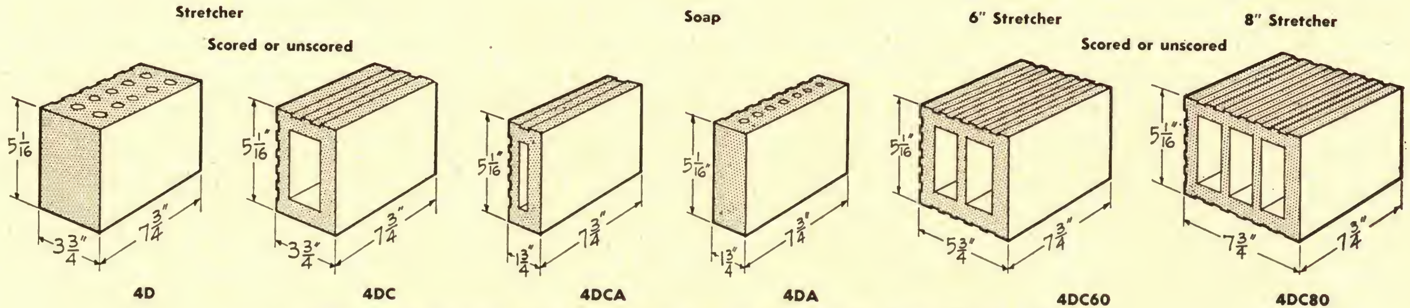


Structural Facing Tile Stretcher Units 5⅓ × 12-in. Face ("6T" Series)

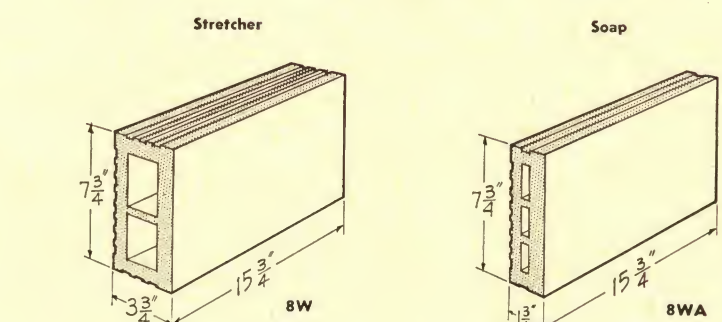


Structural Facing Tile Stretcher Units 4 × 12-in. Face ("6P" Series)

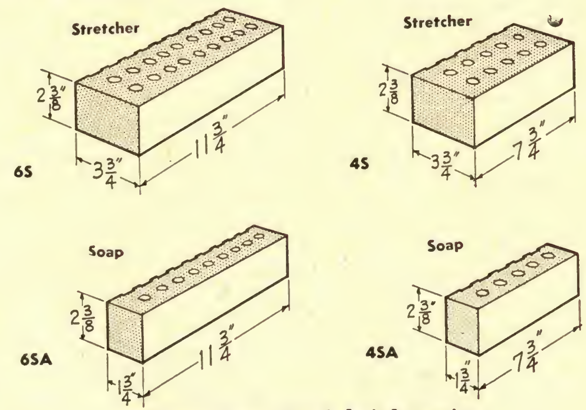
FIG. 8-25



Structural Facing Tile Stretcher Units 5⅓ × 8-in. Face ("4D" Series)



Structural Facing Tile Stretcher Units 8 × 16-in. Face ("8W" Series)



Supplementary Brick-height units

FIG. 8-26

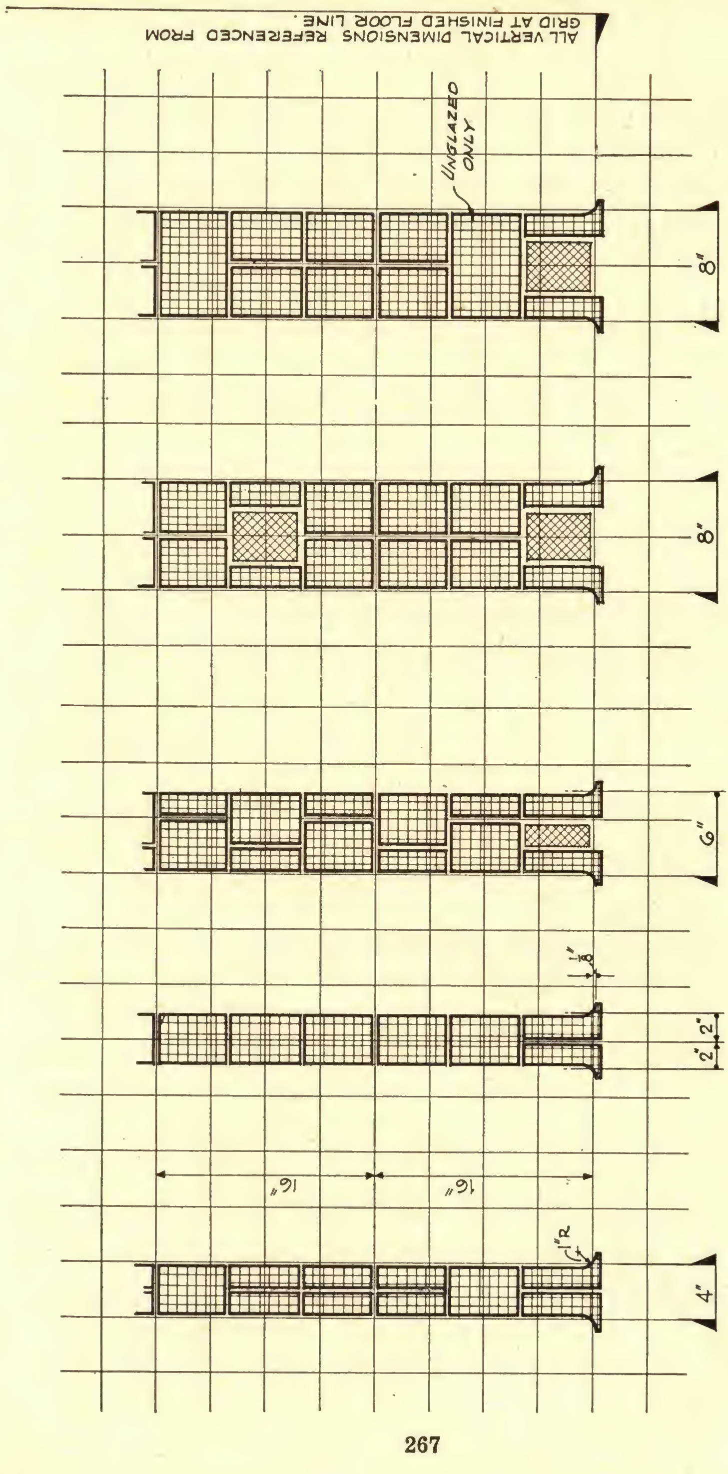


FIG. 8-27
Double faced partition and wall sections

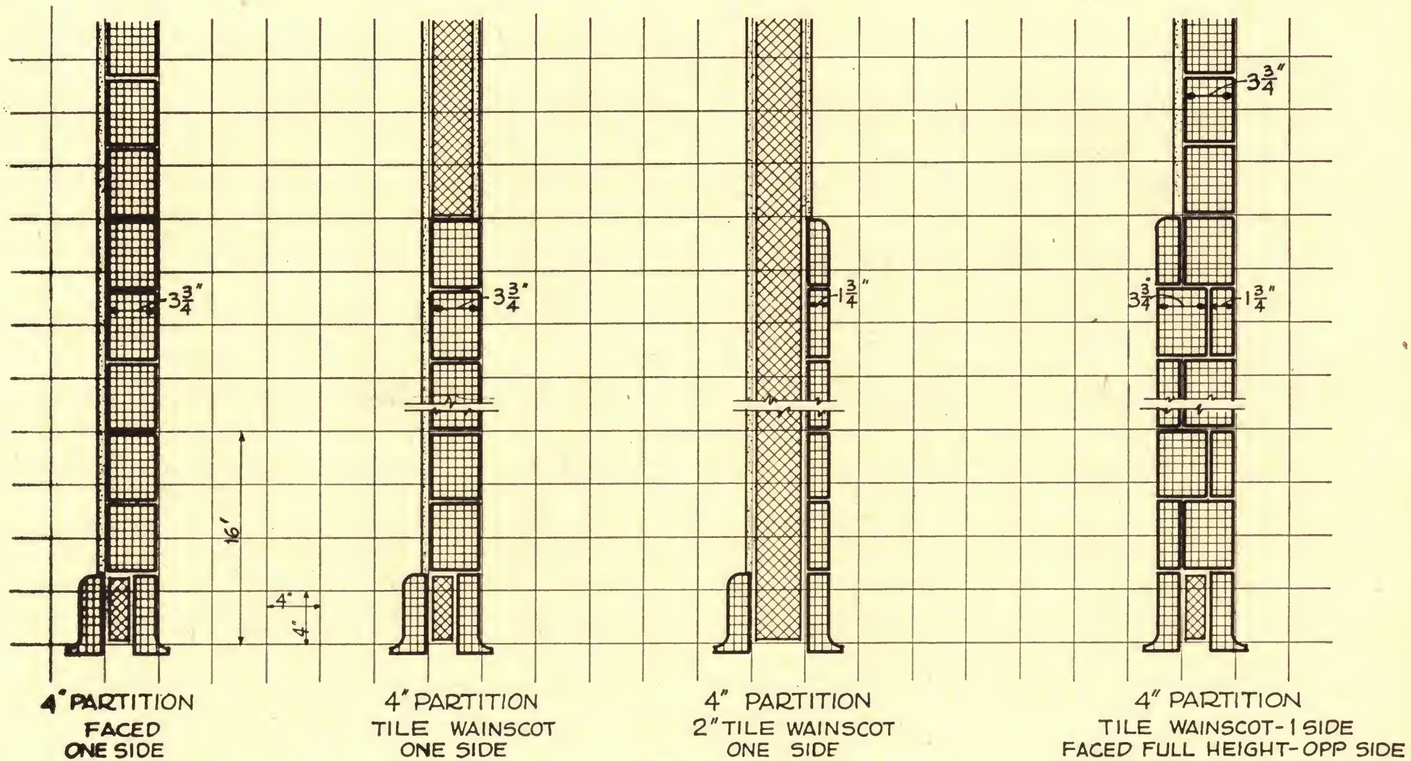


FIG. 8-28

Typical 4-in. partitions and wainscots

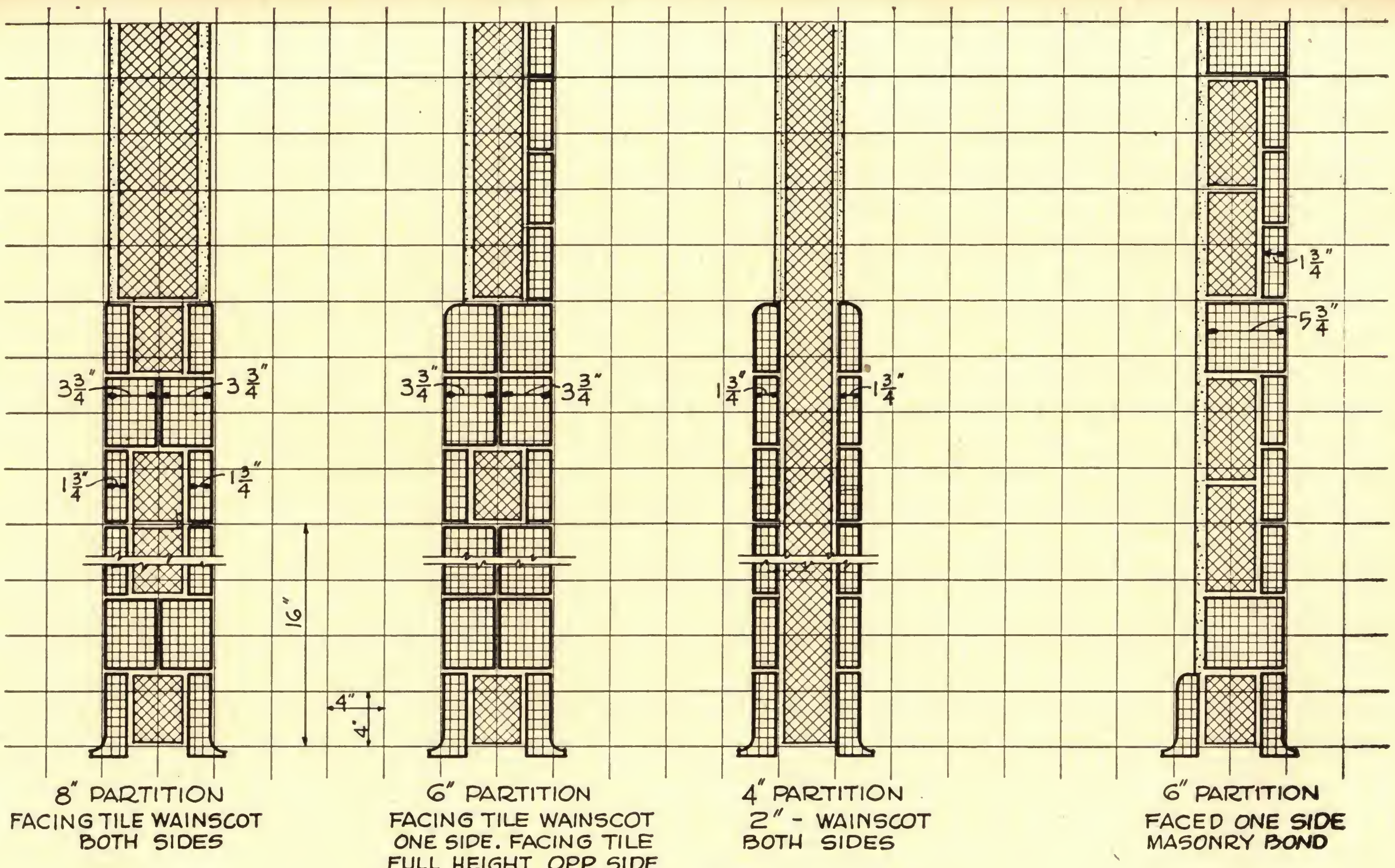
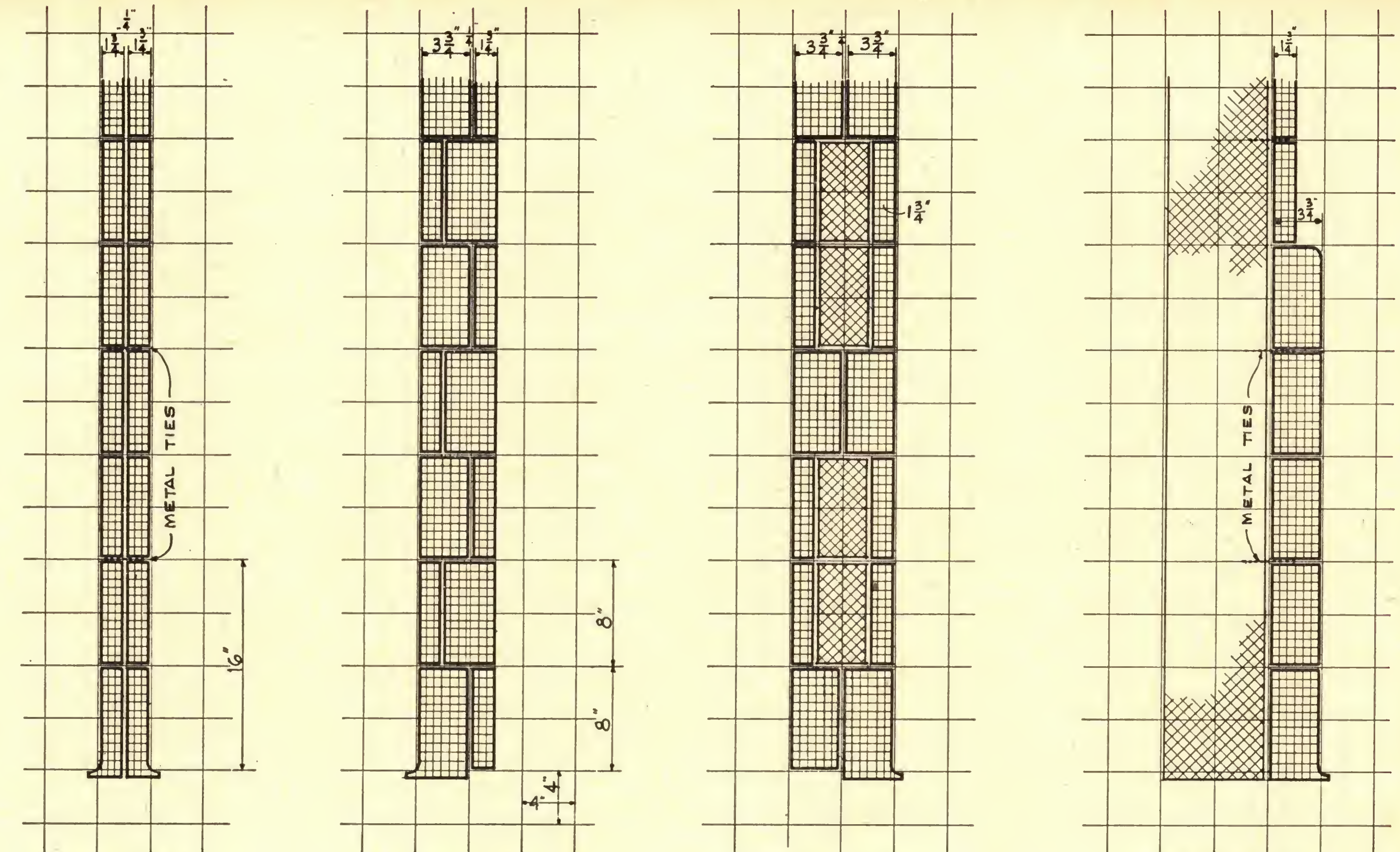


FIG. 8-29

Details showing faced and masonry bonded partitions and wainscots in 4-in., 6-in. and 8-in. thicknesses



4" PARTITION FACED TWO SIDES

6" PARTITION FACED TWO SIDES

8" PARTITION FACED TWO SIDES

2" SOAPS ABOVE 4" WAINSCOT

FIG. 8-30

Typical partition and wall sections with structural facing tile units, 8-in. nominal height—(Series "8W")

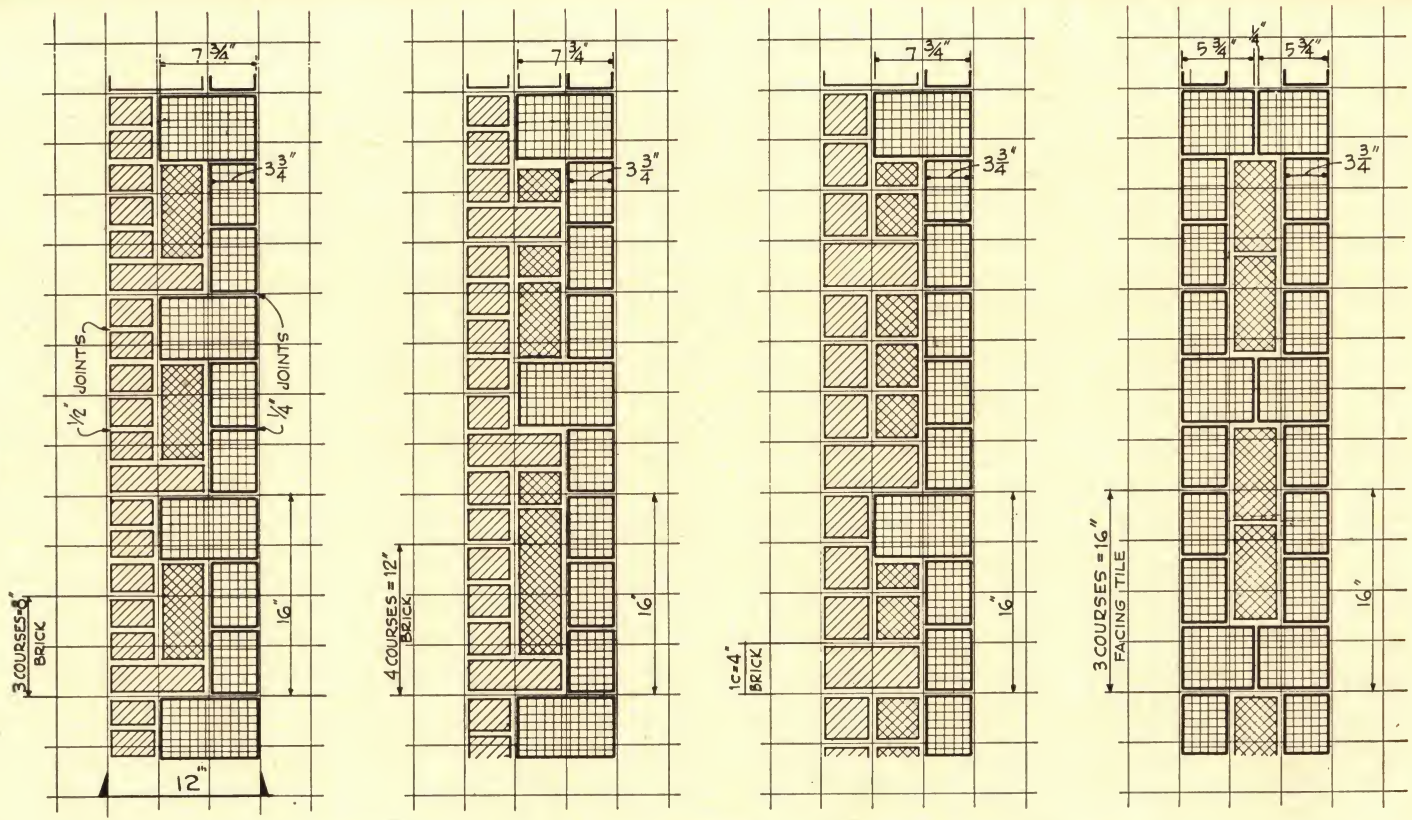


FIG. 8-31

Typical 12-in. masonry bonded load-bearing wall sections showing various sizes of modular masonry unit exterior facings and nominal 5⅓-in. height facing tile interior—("6T and "4D" Series)

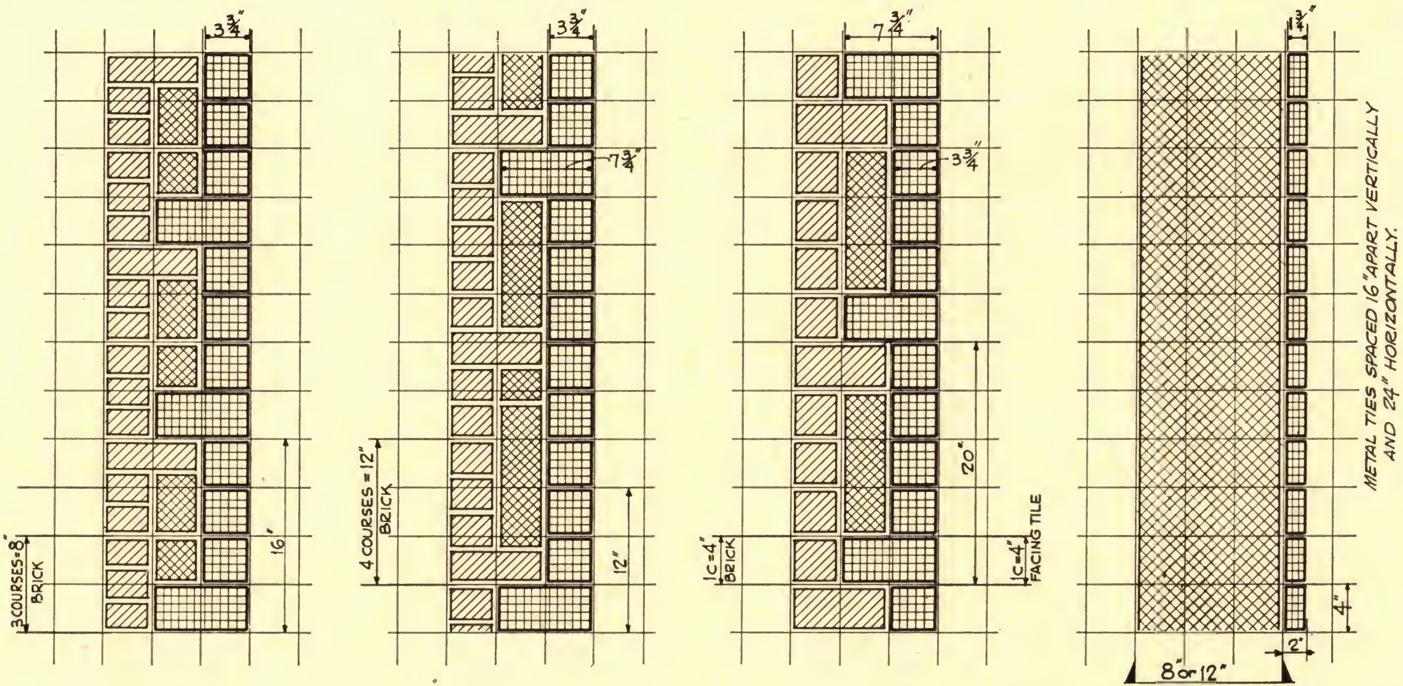


FIG. 8-32

Typical 12-in. masonry bonded load-bearing wall sections showing various sizes of modular masonry unit exterior facings and nominal 4-in. height facing tile interior—("6P" Series). Section at right shows typical veneered construction using 2-in. "soaps"—furnished in 4-in., 5⅓-in. and 8-in. heights

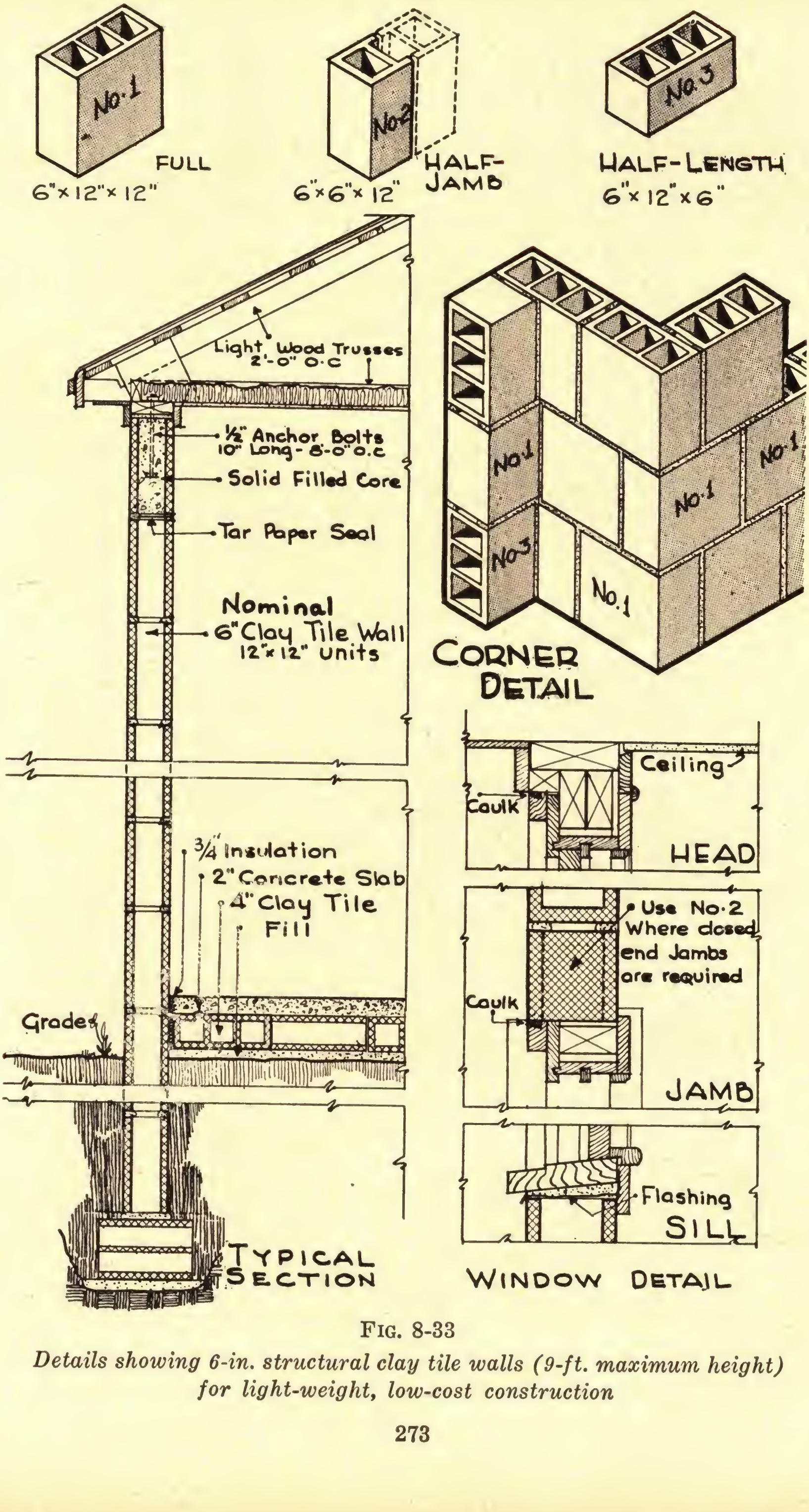


FIG. 8-33

Details showing 6-in. structural clay tile walls (9-ft. maximum height) for light-weight, low-cost construction

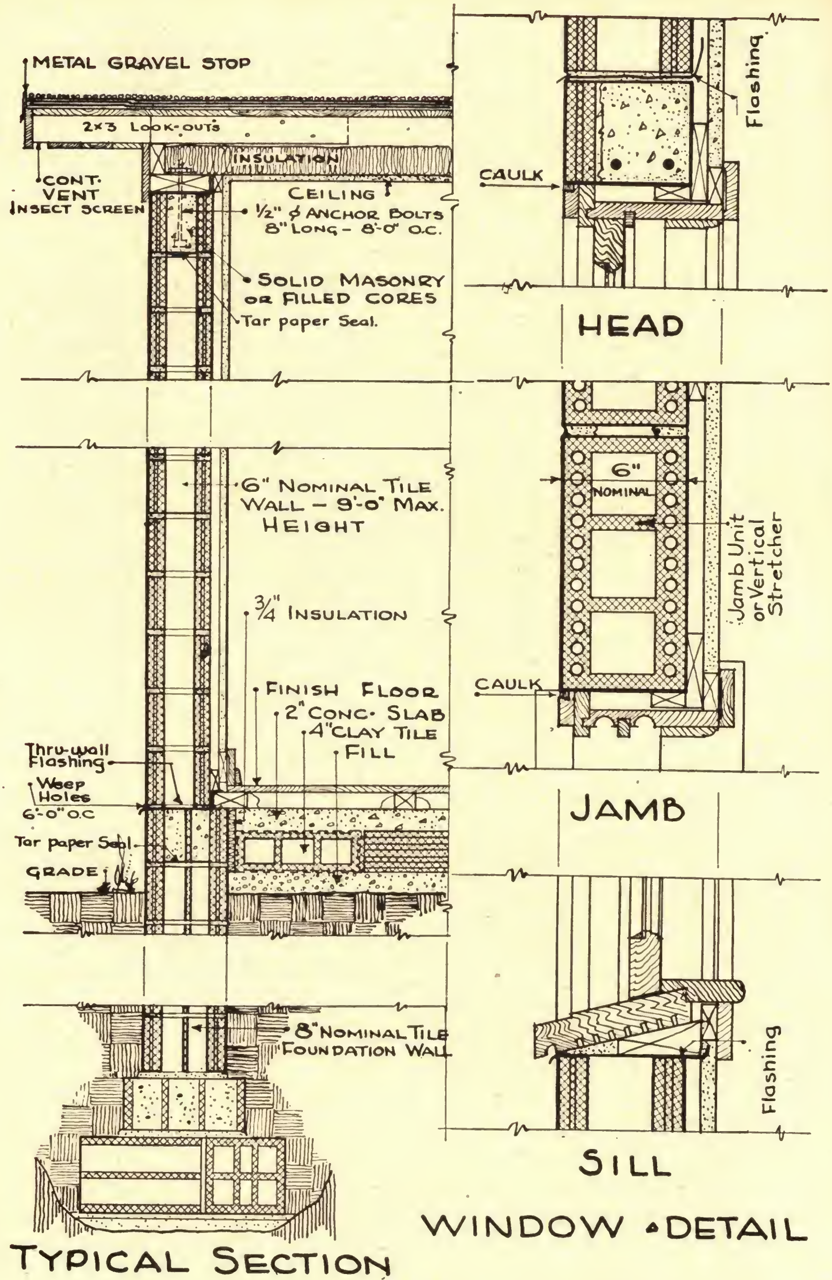


FIG. 8-34

Single-story flat roof construction showing tile insulated floors at grade and furred 6-in. structural facing tile walls

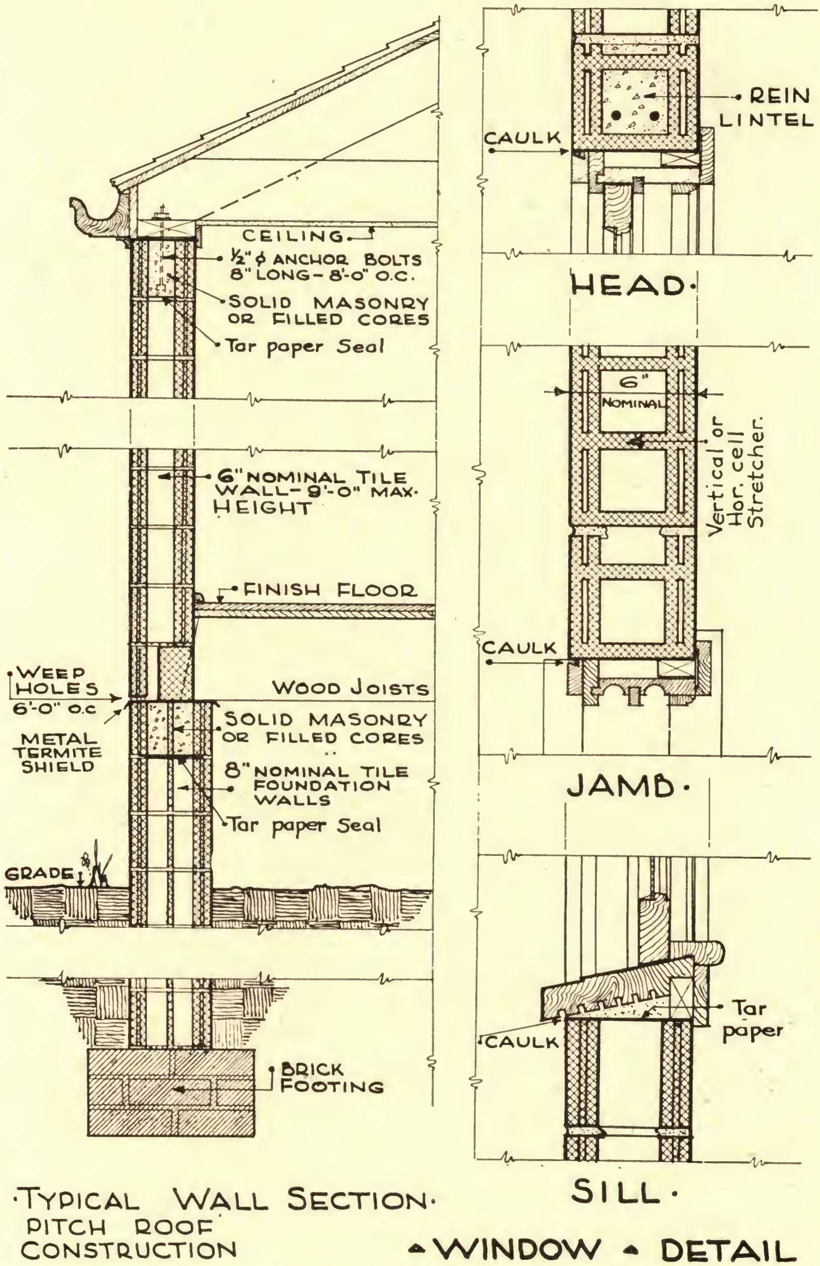


FIG. 8-35

Typical single-story pitch roof construction showing 6-in. exterior and interior exposed, structural facing tile walls

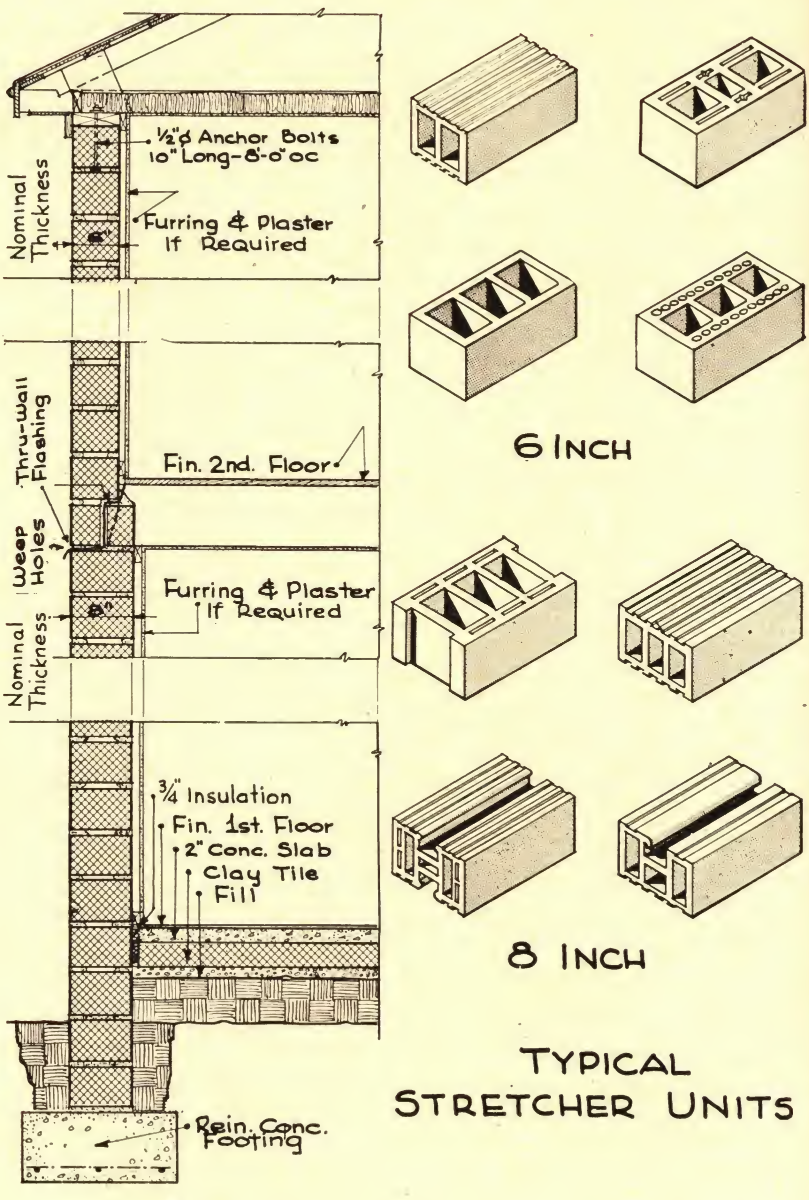


Fig. 8-36

Two-story construction showing the use of 6-in. structural clay tile for second-story above 8-in. foundation and first-story walls

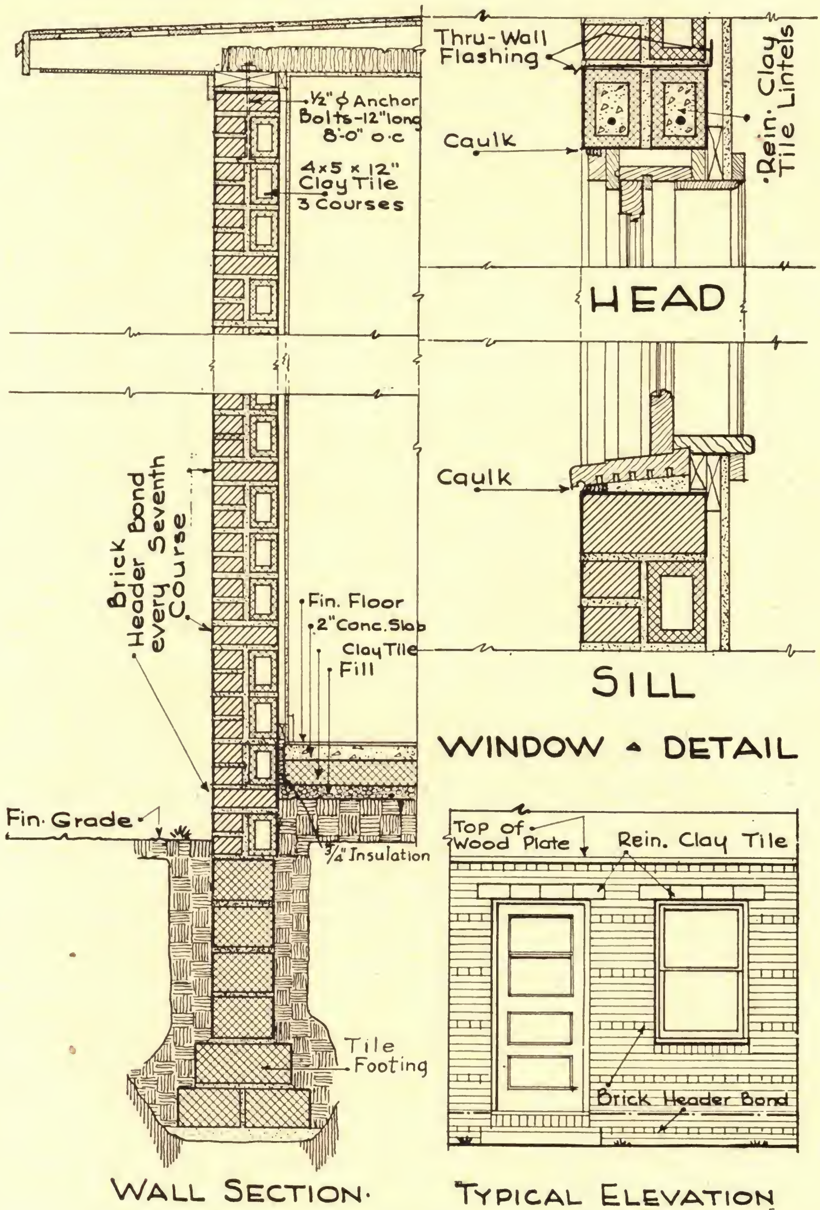


FIG. 8-37

Typical details for nominal 8-in. brick and tile combination wall construction

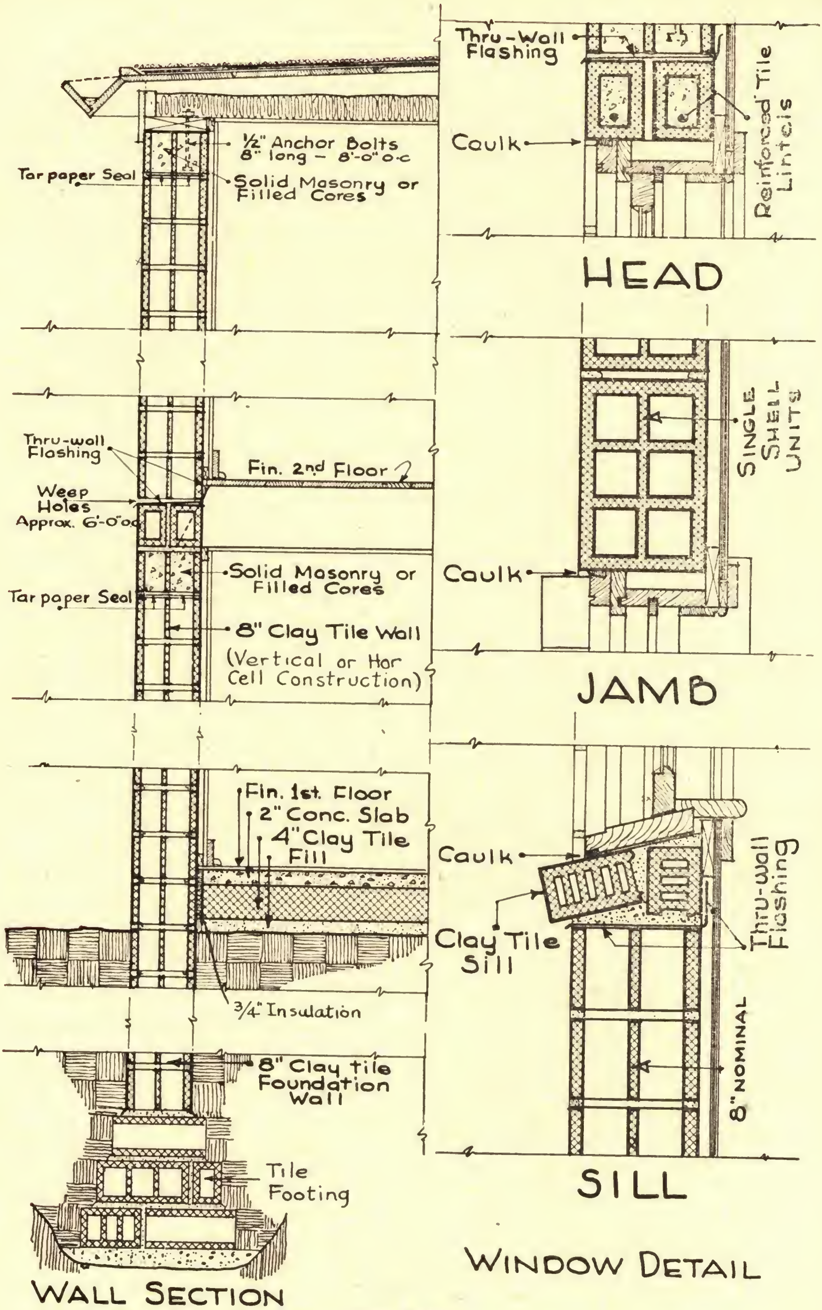


FIG. 8-38

Wall and window details for typical two-story construction showing furred 8-in. structural facing tile walls

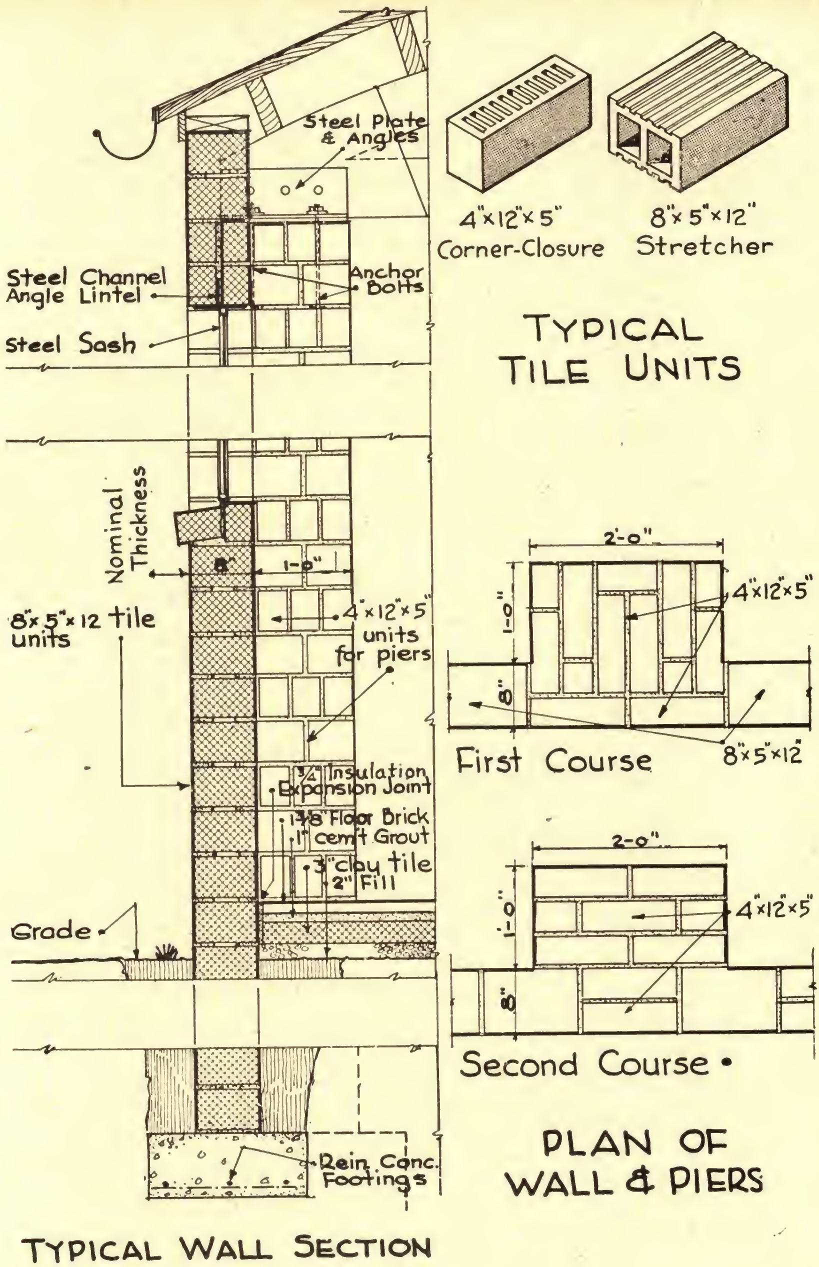


Fig. 8-39

Structural clay tile wall and pilaster construction for heavy industrial buildings

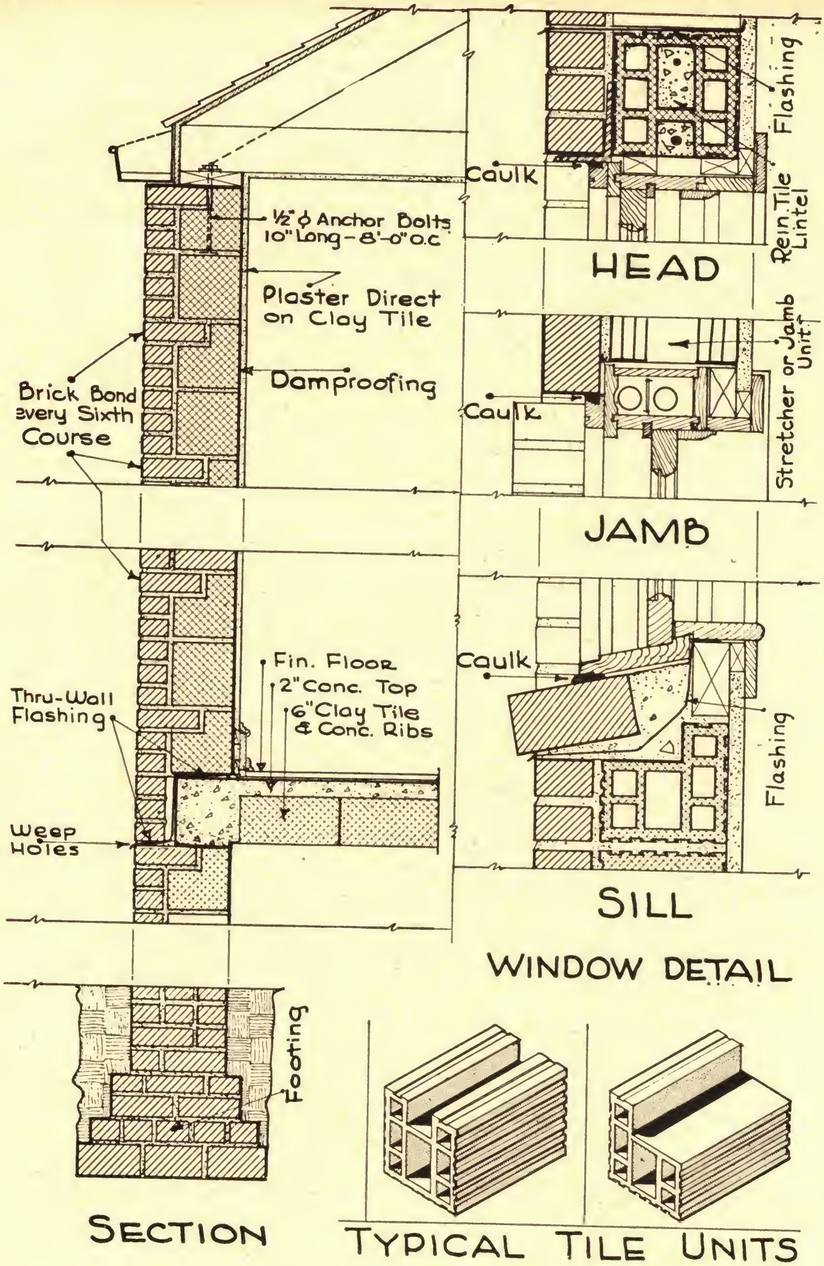


FIG. 8-40

Typical details for nominal 12-in. brick and tile combination wall multiple story construction

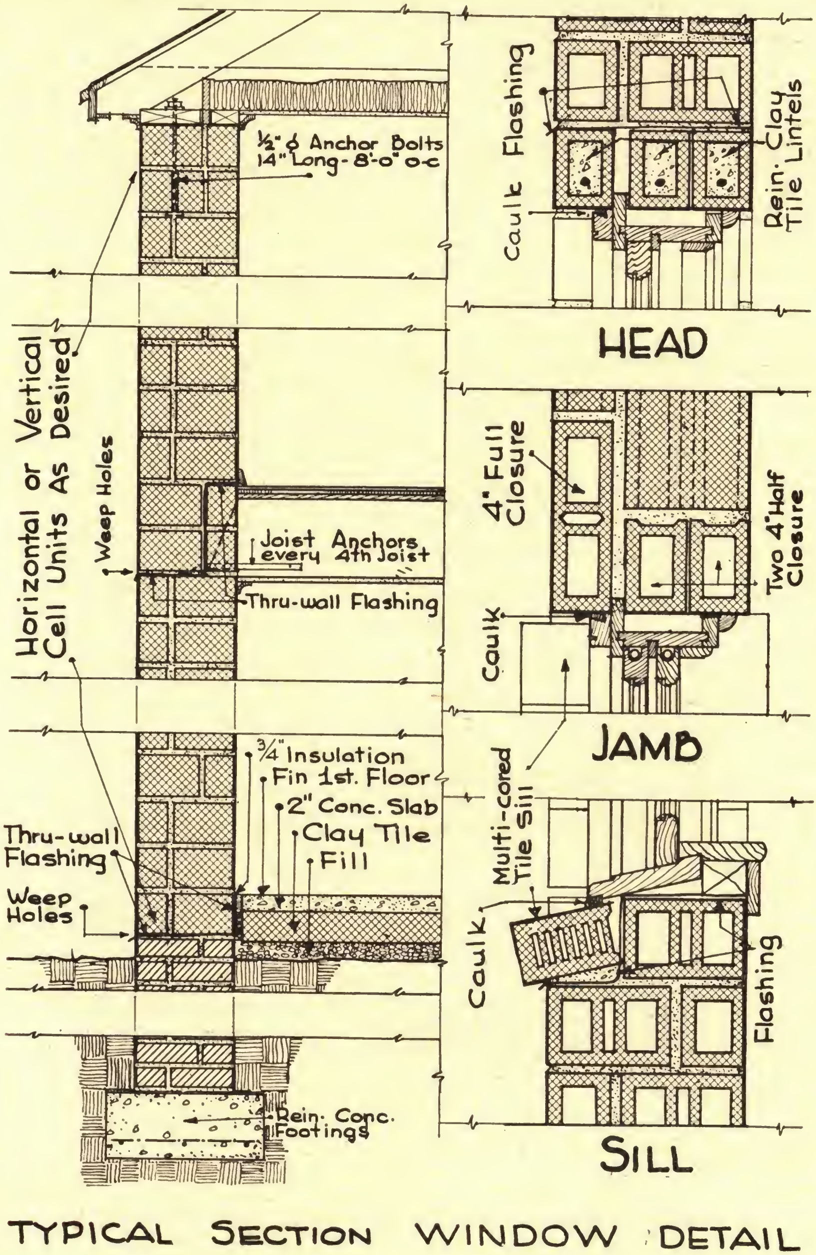


FIG. 8-41

Details showing nominal 12-in. structural clay tile bonded walls for multiple story construction

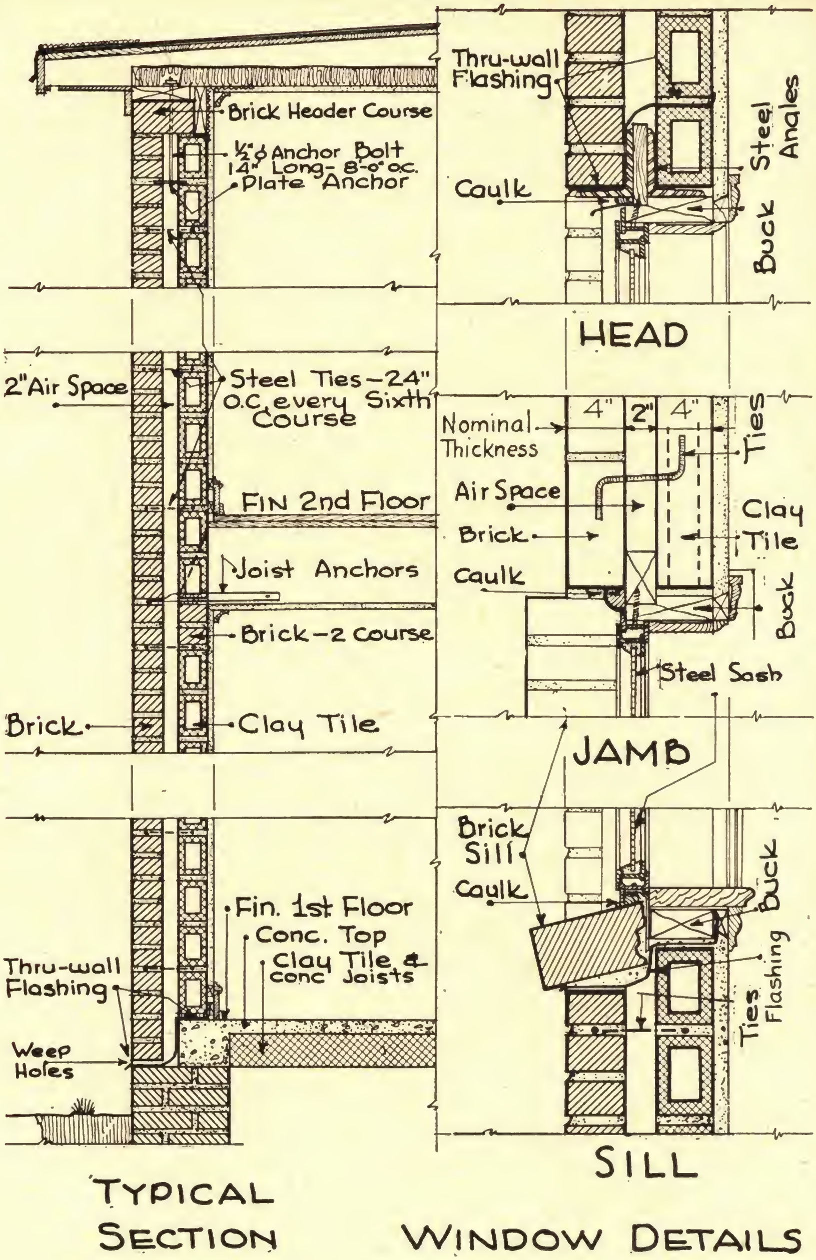


FIG. 8-42

Nominal 10-in. brick and tile cavity wall construction

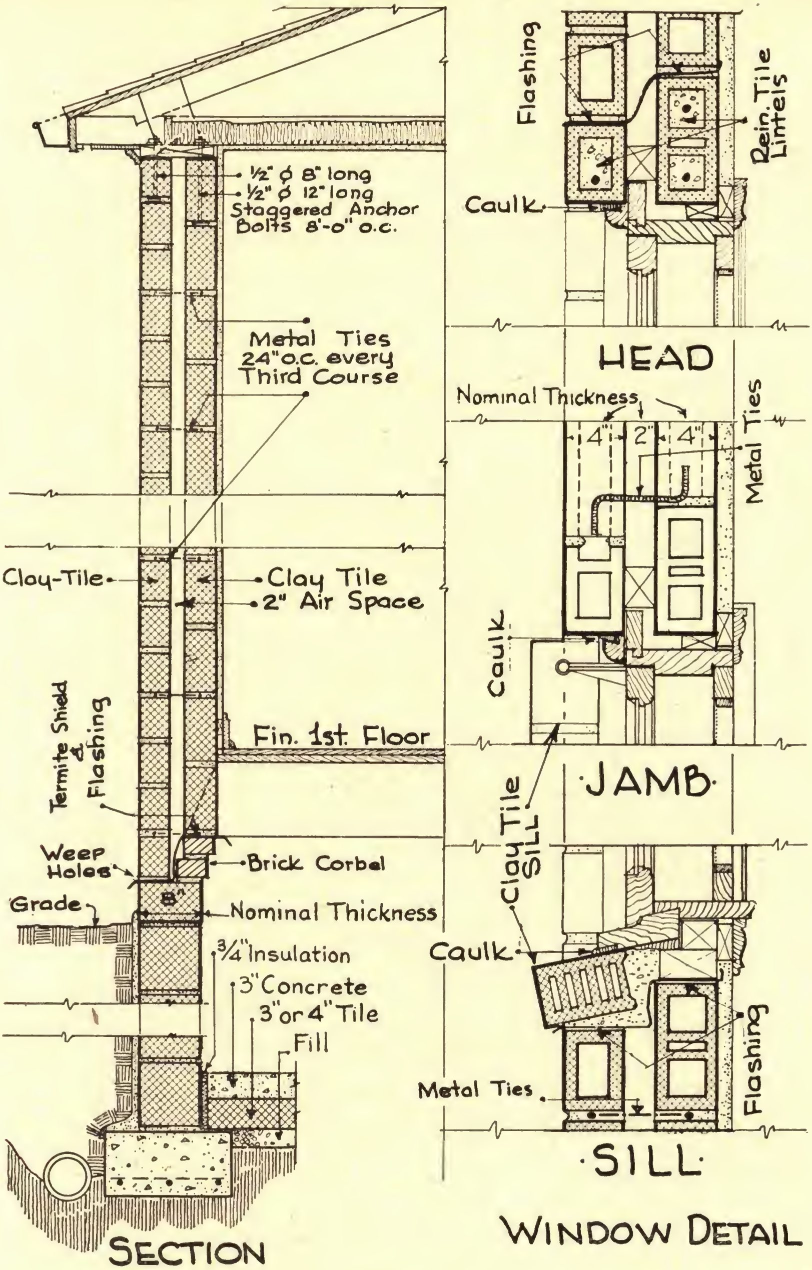


FIG. 8-43

Details showing nominal 10-in. structural clay tile cavity wall on 8-in. tile foundation wall corbelled for support of inner masonry wythe

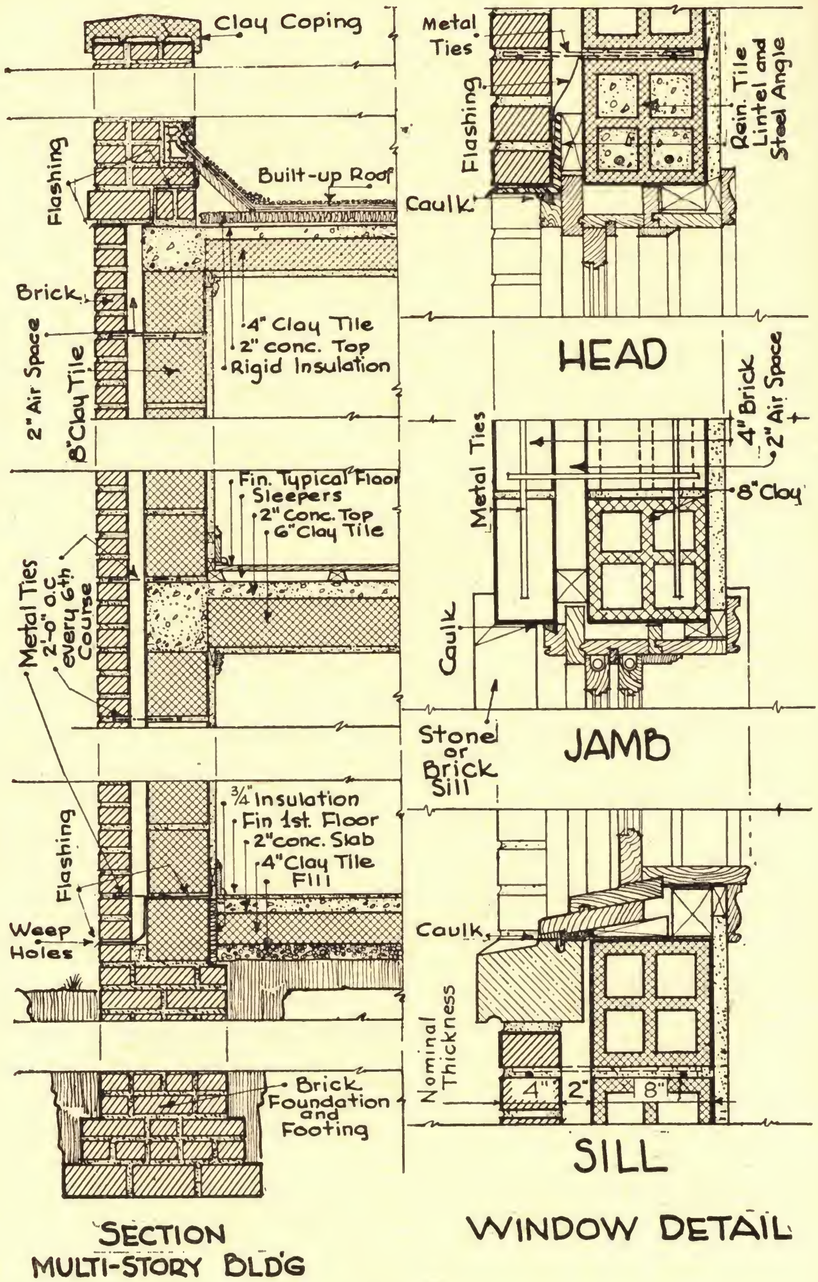


FIG. 8-44

Nominal 14-in. brick and tile cavity wall for multiple story building construction

CHAPTER 9

DESIGN OF CHIMNEYS AND FIREPLACES

901. GENERAL

The loss of life and property due to fires resulting from defective chimneys is staggering. Statistics of the National Fire Protection Association show that, in 1947, 75,000 fires resulting in a monetary loss of 73 million dollars were caused by defective and overheated chimneys and defective and overheated heating equipment. Estimates based on these statistics and the statistics for residential fires, 250,000 in number, indicate that upwards of 50,000 fires in one- and two-family houses were due to these causes.

The fire hazard of defective chimneys has long been recognized by those interested in fire protection and building construction, and in 1920 the National Board of Fire Underwriters published "A Standard Ordinance for Chimney Construction". This ordinance with some revisions has been reprinted four times and over 150,000 copies have been distributed.

The Standard Ordinance specifies methods of constructing chimneys and adjacent parts of the structure to reduce fire hazard and includes recommended chimney heights and flue sizes to provide satisfactory drafts. Provisions of the Standard Ordinance are, in the main, based on observations of field practice and study of individual fires and, while they specify construction far superior to much that has been built in the past, scientific data are needed as a basis for more adequate designs, particularly as to the size of flues required to carry off products of combustion, and heights of chimneys and flue gas temperatures required to produce adequate drafts.

In the appendix of the Standard Ordinance for Chimney Construction, the National Board of Fire Underwriters state: "Faulty operation of flues serving heating systems is largely attributable to a lack of uniform methods for calculating chimney sizes. It is hoped that research work will incorporate the best principles of all methods into a generally recognized standard. A recommendation thus substantiated will be welcome for inclusion in this ordinance and would be considered sufficient excuse for a new edition."

Recently the Housing and Home Finance Agency initiated a comprehensive test program at the National Bureau of Standards for the collection of reliable scientific data on residential chimneys. The report of the tests completed to date (1950) has been published by the Housing and Home Finance Agency as Technical Paper No. 13, "Performance of Masonry Chimneys for Houses", by Robert K. Thulman, and while the data obtained still leave many design questions unanswered, they point the way to substantial improvements in chimney design, both in improving draft, with the resulting more efficient operation of heating appliances, and in reducing fire hazard.

902. CHIMNEY PERFORMANCE TESTS

(a) The scope of the chimney performance tests, initiated by the Housing and Home Finance Agency at the National Bureau of Standards, is outlined in the report, HHFA Technical Paper No. 13, by Robert K. Thulman as follows:

"The scope of this program is intended to include investigation of residential chimneys within three ranges of flue gas temperatures.

"The first, or operating range, embraces flue gas temperatures to which a chimney may be exposed when house-heating equipment operating in a normal manner is connected to it. At the temperatures encountered under this condition the primary interest of the investigation lies in the functional performance of the chimney as a draft producer.

"The second range includes temperatures generally above the operating range and is calculated to include the extreme temperatures and their probable duration, which occur with overfiring of house-heating equipment, either accidentally, deliberately or through inexpert operation. The primary concern of the investigation at this range of temperatures is fire hazard and includes observation of the performance of the chimney as a means to carry products of combustion at high temperature from the breeching to a point outside the house where they may be discharged safely. Since this normally vertical flue is surrounded by and often partially supported by building construction, observation of the effect of the heat transferred from the hot gases inside the flue to building construction surrounding or in contact with the chimney is most important.

"The third range of flue gas temperatures is generally below the middle or operating range, and tests within it are expected to disclose the behavior of the chimney when flue gas temperatures approach or fall below their dew point and condensation occurs within the flue. The effect of the acid liquids, formed under these conditions, on lining, mortar and brick is the principal concern of this area of investigation, although the part that chimney construction plays in producing conditions conducive to condensation is also important.

"The scope of the entire test program also includes corollary investigations of chimney capacity in terms of flue gas volume and velocity, and the effect of heat capacity of the chimney structure and time lag in 'heating up' and 'cooling off'."

Two series of tests were included in this investigation. Series (1) consisted of tests on two masonry chimneys of conventional construction; one with a nominal 9x9-in. flue with an internal area of 44 sq. in. and the other with a nominal 9x13-in. flue with an internal area of 77 sq. in. Both chimneys were designed and constructed so that heights of 11.3 ft., 17.2 ft., 22.3 ft., 27.5 ft., and 31.5 ft. could be tested. These heights are typical for one- and one and one-half-story houses with and without basements, and for a two-story basement house.

Both chimneys were tested at rates of gas flow of 18.4 cu. ft. per min. and 67.5 cu. ft. per min. which correspond to fuel consumption rates required to heat houses with heat losses of 50,000 Btu per hr. and 150,000 Btu per hr., respectively.

Series (2) consisted of test on four masonry chimneys with the following flues: Nominal 9x13-in., 77 sq. in. internal area; nominal 9x9-in., 44 sq. in. internal area; nominal 10-in. round, 78 sq. in. internal area; and nominal

7-in. round, 38 sq. in. internal area. All of these chimneys were tested at the one height of 15.5 ft. and at rates of flue gas flow of 20, 45 and 70 cu. ft. per min.

As a result of the data obtained from the series (1) tests, the author states:

1. Flue gas flow rates. "The difference in draft-producing ability of the two flues in terms of mean temperature for both rates of flue gas flow is negligible and the 9x9-in. flue is the equal for draft production of the 9x13-in. size."

2. Loss of heat through chimney walls. "Though the flue gases entered the 9x9-in. chimney at a lower temperature than the 9x13-in. chimney, the temperature gradient was less and the final temperature was higher."

3. Effect of size and volume. "The best performance was obtained by the 9x9-in. flue carrying 67.5 cu. ft. per min. in which the temperature drop is the least of any of the combinations of flue size and flue gas volume. * * * The data indicate that, for the lower flue gas flow rate, a much smaller cross-sectional area than that of the 9x9-in. flue would improve the performance considerably."

The data from series (2) indicate:

4. Effect of shape. "The areas of the two larger flues being approximately the same (77 and 78 sq. in.), an opportunity was afforded to determine the effect of shape. At all three flow rates and at all temperatures tested, the difference of draft produced was negligible, but such little difference as did occur showed that the round shape is slightly better than the rectangular. This comparison is based on chimney construction in which the flue is supported in the shaft by small pieces of excess mortar squeezed out in the bricklaying process."

5. Effect of internal surface area. "When average temperature is plotted against the perimeters and circumferences of the four flues under consideration, the trend of the average temperature curves is definitely upward for all flow rates as the dimension decreases. Extrapolation to the left indicates that the use of far smaller round or square flues than are at present common would improve performance. While the retarding effect of friction may establish a practical lower limit to flue sizes, it is certain that 6-in. diameter, likely that 5-in. diameter and probable that 4-in. diameter flues are adequate for the 20- and 45-cu. ft. per min. flow rates and safe for the higher 70-cu. ft. per min. rate."

The data obtained in series (2) also confirm the findings from series (1) and the author concludes:

"The tests indicate that draft-producing ability is improved by substantial reduction in the cross-sectional area of the flue. While the tests have not shown the limits in terms of flue gas volume to which this reduction can ultimately be carried, they do show that a round 7-in. flue with a cross-sectional area only half that of a rectangular 9x12-in. flue will produce the minimum draft of 0.10 in. with flue gases leaving the appliance at a temperature substantially lower than that required when a 9x12-in. flue is used. There is strong evidence that, for the smaller capacity heating units used in small low-cost houses, performance, economy and safety can be improved by further reduction in cross-sectional area. Modular 8x8-in. or 8x12-in. flue linings can be used to replace the respective counterparts in the non-modular sizes of 9x9 in. and 9x13 in. with better performance, economy and

safety for the smaller capacity heating units. In fact, for the smaller capacity heating devices, the modular 8x8-in. can be safely used where codes at present require a minimum 9x13-in. non-modular flue size."

Regarding the construction of the chimney, the conclusions and recommendations of the report state:

"The tests showed that combustible construction in contact with the surfaces of the standard masonry chimney are subjected to hazardous temperatures. The use of asbestos paper between combustible material and brick does not materially lessen the hazard.

"Tests show that the use of a continuous lining inside the brick-work as required by the National Building Code substantially reduces the hazard.

"The tests showed that the use of insulation between the flue lining and the surrounding masonry construction will improve draft and reduce exposed surface temperature.

"Both the performance and fire hazard tests showed that a substantial portion of the heat in the flue gases is lost through the masonry in the area immediately adjacent to the point where the breeching enters the flue, and that this excessive loss is probably due to turbulence and recirculation within the breeching and flue. The present design practice of continuing the flue below the breeching obviously increases this turbulence. An appropriate means of introducing room temperature air into the breeching should be required on all breechings to which house-heating equipment is attached."

(b) A study of residential chimneys was conducted at Battelle Memorial Institute for Bituminous Coal Research, Inc., to obtain information on the effectiveness of small residential chimneys for hand-fired heating equipment. Data obtained from this study are reported in the paper, "Performance of Residential Chimneys", by L. B. Schmitt and R. B. Engdahl, published in the Journal Section of the November 1948 issue of Heating, Piping & Air Conditioning.

Four chimneys were tested, each 13 ft. high above the thimble and 17 ft. above the floor. Two of the chimneys were conventional brick and clay flue lining construction, one was constructed of lightweight materials and one was an experimental double-wall chimney designed to overcome the effects of wind.

The construction of the two conventional chimneys is described as follows:

"Chimney No. 1, 8 x 8-in. clay flue lining (6¾ x 6¾ in. inside) surrounded by 4-in. thickness of common brick laid in cement mortar. Space (approximately ½ in.) between lining and brick filled with cement mortar.

"Chimney No. 2, same as No. 1, except that flue lining sections were not cemented together and the space between lining and brick was not filled."

In chimney No. 2, the liner was dropped into place and the joints were left unsealed. This is contrary to the requirements of most building codes; however, it was constructed in this manner "in order to check the differences of opinion among heating engineers regarding the desirability of air or mortar surrounding the chimney."

The report states: "Tests were made at a number of nominal inlet temperatures and at various flows. Flue traverses were made at various points along the horizontal flue and vertical chimney to determine the temperature gradient. The efficiency of the chimney was computed from the test data thus obtained as were also the heat loss and the friction loss."

Regarding the effects of construction on the efficiencies of the brick and flue lining chimneys, the report states:

"The effects of the methods of construction on chimney efficiency were analyzed by comparing the results of the performance tests of chimneys No. 1 and No. 2, and the comparison showed that the presence of an air space instead of mortar surrounding the liner in the brick chimney had no effect at all on the chimney operational characteristics. Moreover, there seems to be no appreciable insulating value in the air space. From a mechanical standpoint, therefore, the standard grouted-liner construction is preferable since it holds the liner in place when it becomes cracked."

Summarizing the data, the authors conclude:

"It was found that chimney efficiency varied only slightly with the various chimneys tested, and was not greatly affected by the materials or type of construction. The cross-sectional area did have some effect on the efficiency, but only insofar as it affected the friction and the recirculation losses.

"Recirculation of the flue gases within the chimney and flue pipe was found to have considerable effect on the cooling and the friction losses. The effect of recirculation decreased as the rate of flow increased.

"When the flow of gases was increased beyond approximately 200 lb. per hr. to simulate chimney operation with stoker equipment, the draft and efficiency were found to decrease, the rate of decrease depending upon the inlet temperature. This effect was expected, since friction losses increase as the square of the rate of flow.

"Tests were conducted under simulated wind conditions on the experimental double-walled chimney, and also on a commercial chimney top. Wind was found to have undesirable effects on both the double-walled chimney and the chimney ventilator. It is recognized that wind may have a deleterious effect on the operation of a short chimney because of the low available draft often provided by this type of chimney."

903. SIZES OF FLUES

(a) Standard Modular Sizes. Manufacturers of flue lining have established standard modular sizes which were adopted as the American Standard Sizes of Clay Flue Linings, A62.4, in 1947. The dimensions of these flues coordinate with dimensions of other masonry materials of which the chimney may be constructed and conform to the American Standard Basis for the Coordination of Dimensions of Building Materials and Equipment. Modular sizes of flue linings included in the ASA Standard A62.4 are listed in Table 9-1.

(b) Size of Residential Flues. The 1943 edition of the Building Code of the National Board of Fire Underwriters contains the following requirement:

"The cross-sectional areas of smoke flues shall be designed and proportioned to meet the conditions of temperatures, within and without the flue, thickness of masonry exposure, shape and material of flue and other influences; for solid or liquid fuels they shall be not less than 70 sq. in. for warm air, hot water and low pressure steam heating appliances; not less than 40 sq. in. for ordinary stoves, ranges and room heaters; not less than 28 sq. in. for small special stoves and heaters; not less than 50 sq. in. for fireplaces, but at least one-twelfth of the fireplace opening.

"*Note.* For the determination of the necessary size of flues for given conditions the 'Guide' of the American Society of Heating and Ventilating Engineers may be consulted."

TABLE 9-1

STANDARD SIZES OF CLAY FLUE LININGS

Minimum Net Inside Area (sq. in.)	① Nominal Dimensions (in.)	Outside Dimensions (in.)	Minimum Wall Thickness (in.)	Approximate Maximum Outside Corner Radius (in.)
15	4 x 8	3.5 x 7.5	0.5	1
20	4 x 12	3.5 x 11.5	0.625	1
27	4 x 16	3.5 x 15.5	0.75	1
35	8 x 8	7.5 x 7.5	0.625	2
57	8 x 12	7.5 x 11.5	0.75	2
74	8 x 16	7.5 x 15.5	0.875	2
87	12 x 12	11.5 x 11.5	0.875	3
120	12 x 16	11.5 x 15.5	1.	3
162	16 x 16	15.5 x 15.5	1.125	4
208	16 x 20	15.5 x 19.5	1.25	4
262	20 x 20	19.5 x 19.5	1.375	5
320	20 x 24	19.5 x 23.5	1.5	5
385	24 x 24	23.5 x 23.5	1.625	6

① Cross section flue lining shall fit within rectangle of dimension corresponding to nominal size.

As indicated in HHFA Technical Paper No. 13, this provision results in inconsistencies due to the fact that the volume of flue gases generated by heating units in the various classifications varies materially. Some units which would be classified as "small special stoves" generate a greater volume of flue gas than certain types of warm air furnaces. As a result, the 1949 edition of the NBFU Building Code does not specify definite flue sizes but states: "The cross-sectional area of smoke flues shall be designed and proportioned to meet the conditions of temperatures within and without the flue, thickness of masonry, exposure, shape and material of flue and other influences."

While this provision may be enforceable for large structures built from an architectural or engineered design, it is difficult to enforce for one- and two-family residences, due both to the uncertainty as to the types of heating appliances that will be connected to the chimney and also to the lack of engineering analysis customarily employed in the design of small residences. For this reason, it seems desirable to recommend minimum flue areas, although it is recognized that they must be based on average conditions and that in many instances an engineered design based upon a knowledge of the heating appliances which will be connected to the flue and the volume of flue gases, both minimum and maximum, that they will generate will provide a chimney which will result in more efficient operation of the heating units.

The data reported in HHFA Technical Paper No. 13 seem to indicate conclusively that the sizes of flues for low heat appliances, such as stoves, cooking ranges and warm air, hot water and low pressure steam heating furnaces, may not only be reduced with safety but by so doing "performance, economy and safety can be improved."

While, as indicated in the report, "The tests have not shown the limits in terms of flue gas volume to which this reduction can ultimately be carried, they do show that a round 7-in. flue with a cross-sectional area only half that of a rectangular 9 x 13-in. flue will produce a 0.10-in. draft with flue gases leaving the appliance at a substantially lower temperature." This relative performance was determined with flue gas volumes of 20, 45 and 70 cu. ft. per

min. which covers the range of volume of flue gases generated by many of the low heat appliances designed for residential heating.

In Table 9-2 recommended flue areas are given for the types of appliances formerly listed in the Building Code of the National Board of Fire Underwriters.

TABLE 9-2

FLUE AREAS FOR APPLIANCES

Heating Appliance	Minimum Area of Flue
Warm air furnace, hot water boiler, steam boiler	57 sq. in. (8 x 12-in. modular flue lining)
Solid- or liquid-fuel direct-fired stoves, ranges, and space heaters........	35 sq. in. (8 x 8-in. modular flue lining)

(c) Size of Non-Residential Flues. Chapter 19 of the 1949 edition of the Guide, published by the American Society of Heating and Ventilating Engineers, gives formulae for determining size and height of chimneys when required draft and flue gas volume and temperature are known. Formulae are also given for determining theoretical and actual draft which may be attained in chimneys of given heights and areas.

Since fuel bed draft losses vary greatly for various fuels and different heating devices, required draft will also vary and it is recommended that sizes and heights of large chimneys be based upon an analysis, using formulae similar to those included in the Guide, rather than upon recommended minimum sizes for boilers of various capacities as has often been the practice in the past. The latter procedure will rarely provide the most efficient chimney and, in many instances, the design will be inadequate.

904. CHIMNEY CONSTRUCTION

(a) Chimney Support. Because of the greater mass and height of a chimney, it is quite probable that the load on its foundation will be greater than that on adjoining foundations. For this reason, it is important that consideration be given to the proper design of the footings so the resultant unit load on the ground will be the same for all footings in the building. This will prevent uneven settlement and the possibility of damage to the finished structure.

Masonry chimneys must be supported on solid masonry foundations or self-supporting fireproof construction and never on wooden construction.

The projection of a footing is designed to resist shear, however, the hollow space at the bottom of a chimney is sometimes wider than twice the normal footing projection. If this is the case, the footings should be extended and built as a unit and the center part of the footing pad should be reinforced near the top; or the wall thicknesses may be increased by corbeling out the bottom courses of brick to the required width.

(b) Chimney Base. The base of a chimney containing only flues may be built with the outside walls nominally 4 in. thick. If a fireplace is included in the chimney, the walls at the ends and under the back of the fireplace should be at least 8 in. thick.

The ash pit should have a tight fitting cast-iron clean-out door with frame of the same material, securely anchored in place and set approximately 16 in. above the floor, or, if there is no basement, the cleanout may be located one or two courses above the finished grade line if accessible from the exterior of the building. Flue lining is not required below a point 8 in. under the lowest smoke pipe thimble or flue ring. At the bottom of each flue, other than fireplace flues, a soot pocket and cleanout should be formed. The cleanout should consist of a tight fitting cast-iron door and frame built solidly into the masonry. The top of the door frame should not be more than one brick course below the bottom of the first section of flue lining. The soot pocket should extend to one course below the bottom of the door and should be plastered smooth on the inside. Each flue must be built as a separate unit entirely free from any connection with other flues or openings.

(c) Flue Walls. Chimneys may be built without flue lining provided the flue walls are at least 8 in. thick and that the inner course is of refractory brick. Exposed joints, both inside and outside, should be struck smooth and the inside should not be plastered. Unlined flues are not smooth, and consequently soot accumulates, reducing the flue area and increasing the hazard of chimney fires. The use of flue lining provides a smooth interior surface, increases the efficiency of the flue and reduces fire hazard. The additional cost of flue lining is offset by the reduced thickness of the flue walls, which may be built one brick thick.

In all cases, flue walls must be built with the joints completely filled with mortar, including the joint against the lining. When round flue lining is used, particular care should be taken to insure complete filling of voids against the lining. Leaky joints may permit infiltration of air to reduce the draft, or the passage of flame to adjacent combustible materials, and be the cause of deterioration of the masonry where exposed above the roof.

In large rectangular chimneys, as in apartment buildings, horizontal reinforcing bars are recommended. Such reinforcement, bent to form hoops and spaced every fourth or fifth course, serves to prevent vertical cracking of the flue walls due to temperature differences.

(d) Flue Lining. Flue lining must withstand the action of heat, gases and acids. Clay flue lining, other than for vents, should have a minimum thickness of not less than ⅝ in.

Only whole sound units of lining should be used, and they should be set in Type A or Type B mortar (see Chapter 5) with the joints completely filled and smooth on the inside. Each section of flue lining should be set before the surrounding brickwork reaches the top of the flue lining section below and the brickwork then built around the flue with the space between flue lining and brick slushed full of mortar.

Where offsets or bends are necessary, they should be formed by mitering equally the ends of both abutting sections of lining. This prevents reduction of the flue area, and it is important that the same effective area be maintained for the full height of the flue.

Flue lining can be cut by filling the section with damp sand, tamped solid and tapping a sharp chisel with a light hammer along the line where the cut is desired. No cutting should be done after the lining is built into the chimney, as it will probably be shattered and fall out of place.

In flues connected to heating appliances that will operate with average flue gas temperatures which will reduce the inside flue surface temperature

below 150° F., the flue lining and jointing material should be resistant to the corrosive effects of acids resulting from the condensation of flue gases.

(e) Connections. Standard flue lining sections are available with openings to receive smoke pipe connections, but if the opening is to be cut, it should be done in the manner described in (d) and not after the chimney is built.

The smoke pipe connection should enter the side of the flue through a thimble or flue-ring. Such rings are available with inside diameters of 6 in., 7 in., 8 in., 10 in. and 12 in. and lengths of 4½ in., 6 in., 9 in. and 12 in. These rings should be built in as the work progresses and must be made airtight at all points. The metal smoke pipe should not enter farther than the inner face of the flue, and the joint around the pipe should be made airtight with boiler putty or asbestos cement. The top of the smoke pipe should be not less than 18 in. below the ceiling, and no wood or combustible material should be placed within 6 in. of the thimble.

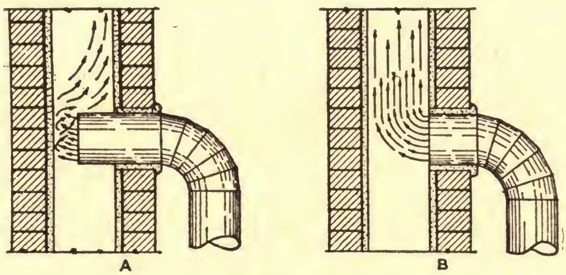


FIG. 9-1

Showing improper (A) and proper (B) connections

(f) Chimney Tops and Flashing. The tops of chimneys above the roof offer unlimited possibilities for architectural treatment by the use of cut or ground brick in addition to the standard shape. In the more ornamental types, round flue lining may be found to be more advantageous and in this event the same round lining should be used for the full height of the flue.

Regardless of the architectural design, certain structural details should always be followed. The flue lining should project 4 in. above the chimney cap or top course of brick and be surrounded with a wash of rich portland cement mortar at least 2 in. thick finished with a straight or concave slope to direct the air current upward at the top of the flue. This wash also serves to drain water from the top of the chimney and it is preferable to form the cap or top courses with sufficient projection to serve as a drip and keep the walls dry and clean. The masonry flue walls and wythes should be well bonded either by carefully staggering the joints or by the introduction of non-corrosive metal ties.

Fire clay chimney tops or pots are available for use on new or old chimneys. Care should be exercised in selecting these units so that the effective area of the flue is not reduced. They are made to fit over the flue linings, one to each flue, and should be set in Type A mortar finished to form a wash as previously described.

At the intersection of chimney and roof, the connection should be made weathertight by means of flashing and counter flashing, preferably of

copper or other rust-resisting metal, arranged to allow for any vertical or lateral movement between the chimney and roof.

(g) **Adjacent Woodwork.** Wood framing and furring members should never be placed closer than 2 in. to the walls of a chimney and this distance should be increased to 4 in. at the backs of fireplaces. The space between chimneys and floor members should be firestopped with an incombustible material supported on strips of metal lath buckled to form a flexible joint.

Plaster may be applied directly on the chimney walls or on metal lath and metal furring.

905. CHIMNEY CODE REQUIREMENTS

The following building code provisions governing the construction of chimneys and adjacent woodwork are quoted from the 1949 edition of the National Building Code recommended by the National Board of Fire Underwriters:

"1. Construction of Chimneys. (a) Chimneys hereafter erected within or attached to a structure shall be constructed in compliance with the provisions of this section.

"(b) Chimneys shall extend at least 3 ft. above the highest point where they pass through the roof of the building and at least 2 ft. higher than any ridge within 10 ft. of such chimney.

"(c) Chimneys shall be properly capped with brick, terra cotta, stone, cast iron, concrete or other approved non-combustible, weatherproof material.

"(d) Chimneys shall be wholly supported on masonry or self-supporting fireproof construction.

"(e) No chimney shall be corbeled from a wall more than 6 in.; nor shall a chimney be corbeled from a wall which is less than 12 in. in thickness unless it projects equally on each side of the wall; provided that in the second story of 2-story dwellings corbeling of chimneys on the exterior of the enclosing walls may equal the wall thickness. In every case the corbeling shall not exceed 1 in. projection for each course of brick projected.

"(f) No change in the size or shape of a chimney, where the chimney passes through the roof, shall be made within a distance of 6 in. above or below the roof joists or rafters.

"2. Chimneys for heating appliances, low heat industrial appliances and portable type incinerators. (a) Chimneys for stoves, cooking ranges, warm air, hot water and low pressure steam heating furnaces, fireplaces, and low heat industrial appliances, other than chimneys for incinerators of non-portable type (see subsection 5), shall be constructed of solid masonry units or of reinforced concrete. The walls shall be properly bonded or tied with corrosion resistant metal anchors. In dwellings and buildings of like heating requirements the thickness of the chimney walls shall be not less than 4 in. In other buildings the thickness shall be not less than 8 in., except that rubble stone masonry shall be not less than 12 in. thick.

"(b) Every such chimney hereafter erected or altered shall be lined with a flue lining conforming to the requirements below.

"(c) Flue linings shall be made of fire clay or other refractory clay which will withstand the action of flue gases and resist without softening or cracking, the temperatures to which they will be subjected, but not less than 2000° F., or of cast iron of approved quality, form and construction.

"(d) Required clay flue linings shall be not less than ⅝ in. thick for the smaller flues and increasing in thickness for the larger flues.

"(e) Flue linings shall be installed ahead of the construction of the chimney as it is carried up, carefully bedded one on the other in type A, type B or fire clay mortar with close fitting joints left smooth on the inside.

"(f) Flue linings shall start from a point not less than 8 in. below the intake, or, in the case of fireplaces, from the throat of the fireplace. They shall extend, as nearly vertically as possible, for the entire height of the chimney and be extended 4 in. above the top or cap of the chimney.

"(g) Cleanouts for flues or fireplaces shall be equipped with cast iron doors and frames arranged to remain tightly closed when not in use.

"(h) When two or more flues are contained in the same chimney, at least every third flue shall be separated by masonry at least 4 in. thick bonded into the masonry wall of the chimney. Where flue linings are not so separated, the joints of adjacent flue linings shall be staggered at least 7 in.

"3. Chimneys for medium heat industrial appliances, and power boilers. Chimneys for high pressure steam boilers, smoke houses and other medium heat appliances, other than incinerators, shall be of masonry or reinforced concrete not less than 8 in. thick; provided that stone masonry shall be not less than 12 in. thick; and in addition, shall be lined with not less than 4½ in. of fire brick laid on the 4½-in. bed in fire clay mortar, starting not less than 2 ft. below the smoke pipe entrance and extending for a distance of at least 25 ft. above the smoke pipe entrance.

"4. Chimneys for high heat industrial appliances. Chimneys of cupolas, brass furnaces, porcelain baking kilns and other high heat appliances shall be built with double walls, each not less than 8 in. in thickness, with an air space of not less than 2 in. between them. The inside of the interior walls shall be of fire brick not less than 4½ in. in thickness laid on the 4½-in. bed in fire clay mortar.

"5. Chimneys for incinerators of non-portable type. (a) Chimneys for non-fuel fired incinerators in which the grate of the combustion chamber does not exceed 9 sq. ft., in residence buildings, institutional buildings, churches, schools and restaurants, shall be of solid masonry or of reinforced concrete not less than 4 in. thick with a flue lining as specified in subsection 2.

"(b) Chimneys for non-fuel fired incinerators in which the grate of the combustion chamber exceeds 9 sq. ft., in residence buildings, institutional buildings, churches, schools and restaurants, shall be of solid masonry or of reinforced concrete not less than 4 in. thick with a lining of fire brick not less than 4½ in. thick laid on the 4½-in. bed for a distance of not less than 30 ft. above the roof of the combustion chamber, and in clay or shale brickwork not less than 8 in. thick beyond 30 ft. above the roof of the combustion chamber.

"(c) Chimneys for fuel fired incinerators shall be as required for non-fuel fired incinerators with grates exceeding 9 sq. ft., but the fire brick lining shall extend for not less than 40 ft. above the roof of the combustion chamber.

"(d) Chimneys for incinerators other than covered above shall be of solid masonry or of reinforced concrete not less than 8 in. thick and have a lining of fire brick not less than 4½ in. thick laid on the 4½-in. bed in fire clay, for the full height of the flue.

"(e) Nothing in this section shall prohibit the connection by means of an approved smoke pipe or breeching, of an incinerator to a smoke stack

or chimney serving a heat appliance provided the cross-sectional area of such stack or chimney is at least 4 times that of the incinerator breeching and such stack or flue meets the requirements for the incinerator so connected.

"(f) All flues for non-fuel fired incinerators shall terminate in substantially constructed spark arresters.

"6. Sizes of flues. (a) The cross-sectional areas of smoke flues shall be designed and proportioned to meet the conditions of temperatures, within and without the flue, thickness of masonry, exposure, shape and material of flue and other influences.

"(b) The cross-sectional areas of flues and vents for gas burning appliances shall be not less than 1 sq. in. per 7500 hourly Btu imput and in no case shall this section be less than 3 in. in diameter. Flues and vents shall have cross-sectional areas at least equal to the aggregate areas of the vents of the appliances connected to them.

"7. Use of flues. (a) It shall be unlawful to use as a smoke flue, a flue hereafter constructed or placed in a building, or a flue now existing that is not already used as a smoke flue, unless it conforms to the requirements of this section.

"(b) Chimneys or flues installed for the use of gas appliances but which are not suitable for solid or liquid fuels, shall be plainly and permanently labeled, "This flue is for the use of gas burning appliances only." The label shall be attached at a point near where the vent pipe enters the chimney, or with type B gas vents used in place of a chimney, at a point near where the type B gas vent enters a wall, floor or ceiling.

"8. Flues to be clean. (a) Upon the completion of a building or the alteration of existing flues, the flues shall be cleaned and left smooth on the inside.

"(b) The building official may require an inspection to be made to assure safe condition of the flue before permitting its use.

"9. Fireplaces. (a) The back and sides of fireplaces hereafter erected shall be of solid masonry or reinforced concrete, not less than 8 in. in thickness. A lining of fire brick at least 2 in. thick or other approved material shall be provided unless the thickness is 12 in.

"(b) Fireplaces shall have hearths of brick, stone, tile or other approved non-combustible material supported on a fireproof slab or on brick trimmer arches. Such hearths shall extend at least 20 in. outside of the chimney breast and not less than 12 in. beyond each side of the fireplace opening along the chimney breast. The combined thickness of hearth and supporting construction shall be not less than 6 in. at any point.

"(c) Wooden forms or centers used in the construction of that part of the supporting construction which is below the hearth of the fireplace shall be removed when the supporting construction of the hearth is completed.

"(d) No heater shall be placed in a fireplace which does not conform to the requirements of this section or is not provided with a flue, except electric or gas heaters of a type specifically approved for such installation.

"(e) Spaces between the chimney and joists, beams or girders and any combustible materials shall be firestopped by filling with non-combustible material."

* * * * *

"Framing around chimneys and fireplaces. (a) All wooden beams and joists shall be trimmed away from chimneys and fireplaces. Headers, beams and joists shall be not less than 2 in. from the outside face of a chimney or from masonry enclosing a flue. Headers supporting trimmer arches at

fireplaces shall be not less than 20 in. from the face of the chimney breast. Trimmers shall be not less than 6 in. from the inside face of the nearest flue.

"(b) No woodwork shall be placed within 4 in. of the back face of a fireplace; nor shall combustible lathing, furring or studding be placed against a chimney; but this shall not prevent plastering directly on the masonry or on metal lath and furring.

"(c) No wooden mantel or other woodwork shall be hereafter placed within 8 in. of either side nor within 12 in. of the top of a fireplace opening.

"(d) All spaces between the masonry of chimneys or flues and wooden joists, beams or headers shall be firestopped by filling with non-combustible material.

"(e) All spaces back of combusible mantels shall be filled with non-combustible material."

906. CHIMNEY TEST AND REPAIR

(a) Smoke Test. After the chimney has been completed and the mortar thoroughly hardened and before any appliances are connected, a smoke test should be made on each flue. This is done by building a smudge fire at the bottom of the flue, and, while the smoke is flowing freely from the flue, cover the top tightly. Escape of smoke into other flues or through the chimney walls indicates openings that must be made tight before the chimney is accepted. The test should be made by the mason contractor and observed by representatives of the building department and the owner.

Repairing of leaks is usually difficult and expensive, and it is, therefore, much more satisfactory and economical to see that construction is properly executed as the work progresses.

(b) Cleaning Flues. Smoke passage and chimney flues should be kept clean. An accumulation of soot may cause a chimney fire with consequent danger of sparks igniting the roof or damage to the chimney itself which would permit passage of fire through the fire walls.

The most efficient method of cleaning a chimney flue is by means of a weighted brush or bundle of rags lowered and raised from the top.

(c) Repairing Chimneys. The tops of unlined chimneys may have to be rebuilt every few years due to the disintegrating effect of smoke and gases on the mortar. The chimney should be taken down to a point where the mortar joints are solid. The new top should be built with fire clay flue lining of the same size as the old flue, the construction being as previously described.

907. FIREPLACES

The building of a fireplace that will perform properly and satisfactorily is not a mysterious operation nor dependent upon luck. On the contrary, the essentials of correct design are but few and simple. The principal results to be achieved are:

1. Proper combustion of the fuel.
2. Delivery of all smoke and other products of combustion up the chimney.
3. Radiation of the maximum amount of heat into the room.
4. Simplicity and fire-safeness in construction.

Of these, 1 and 2 are closely related and depend mainly upon the shape and relative dimensions of the combustion chamber, the proper location of the

fireplace throat, and its relation to the smoke shelf, and the ratio of the flue area to fireplace opening area. Three is dependent upon the shape and dimensions of the combustion chamber, and four is subject to the size and shape of the masonry units used and their ability to withstand high temperatures without warping, cracking or deterioration.

(a) Sizes of Fireplaces. Careful consideration should be given to the size of fireplace best suited to the room in which it is located, not only from the viewpoint of its appearance but of its operation as well. If it is too small, it may function properly but will not produce a sufficient amount of heat. If too large, a fire that would fill the combustion chamber would be entirely too hot for the room. Moreover, it would require a larger chimney and induce an abnormal infiltration of air through doors and windows to supply the needs for combustion and so waste fuel.

A room with 300 sq. ft. of floor area is well served by a fireplace with an opening 30 in. to 36 in. wide. For larger rooms the width may be increased, but all other dimensions should be taken from Table 9-3 for the width opening selected.

Fireplace openings should not be too high; for the usual width of opening, the height above the hearth is seldom more than 32 in. The first two columns of Table 9-3 give the widths and corresponding heights of fireplace openings found to be the most satisfactory for appearance and efficient operation. These dimensions may be varied slightly to meet regular brick courses and joints, especially where the facing or trim is of brick.

(b) Combustion Chamber. The shape of the combustion chamber influences both the draft and the amount of heat radiated into the room. The correct splays and slopes are shown in Fig. 9-2 and 9-3, and the corresponding dimensions are given in Table 9-3. Again these dimensions might be varied slightly but the information given is based on years of experience and it is inadvisable to make any great changes. The slope of the back throws the flame forward and leads the gases with increasing velocity through the throat. It also, with the splay of the sides, gives the maximum radiation of heat into the room. The combustion chamber should be lined with firebrick laid with thin joints of fireclay mortar. The back and end walls of the average size fireplace should be at least 8 in. thick, and thicker for larger sizes, to support the chimney load above.

TABLE 9-3

BASIC FIREPLACE DIMENSIONS ①

(A)	(B)	(C)	(D)	(E)	(F)	
					Flue	
Width in.	Height in.	Depth in.	Back in.	Dome in.	Square nominal, in.	Round nominal, in.
30	30	16	17	25	8 x 12	10
32	30	16	19	26	8 x 12	10
34	30	16	21	28	8 x 12	10
36	30	16	23	28	12 x 12	12
40	30	16	27	32	12 x 12	12
42	33	16	29	35	12 x 12	12
48	33	18	33	40	12 x 12	12

① See Fig. 9-2.

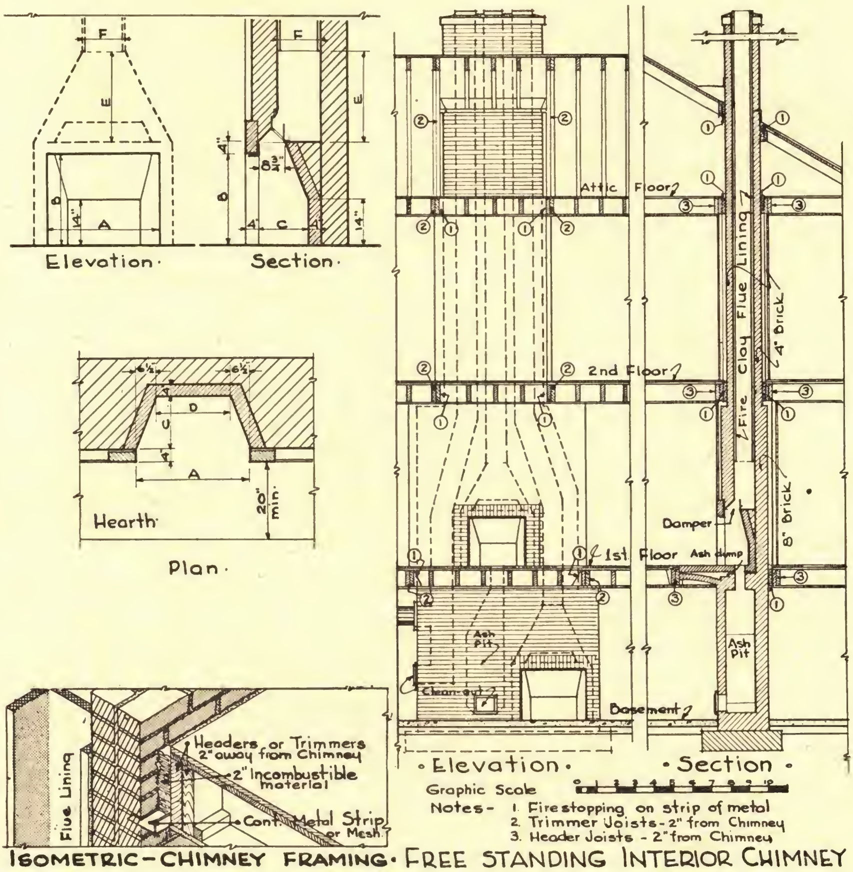


FIG. 9-2

Fireplace dimensions and details

(c) Throat. Because of its effect on the draft, the throat of the fireplace should be carefully designed. It should be not less than 4 in. and preferably 8 in. above the highest point of the top of the fireplace opening. The sloping back extends to the same height and forms the support for the back of the damper. A metal damper should be placed in the throat, extending the full width of the fireplace opening, preferably of a design in which the valve plate opens upward toward the back. Such a plate when open forms a barrier to stop down draft and deflect it upward into the ascending column of smoke. When the fireplace is not in use, the damper should be kept closed to stop drafts and heat loss from the room as well as to keep out dirt from the flue.

Metal dampers are available in several types, some forming in one piece the damper throat and supporting lintel over the fireplace opening. This type has the advantage of producing a smooth throat passage and simplifying the masonry work.

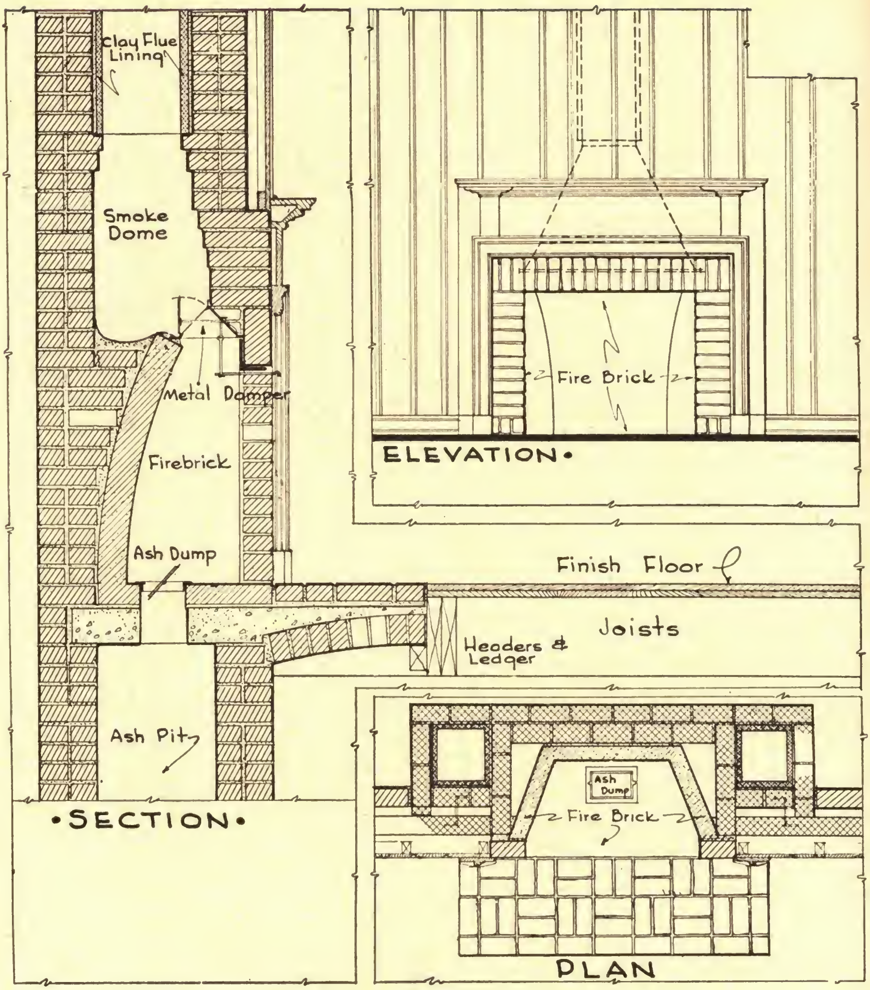


FIG. 9-3

Construction details of a typical fireplace

(d) Smoke Shelf and Chamber. The location of the throat establishes the position of the smoke shelf. This shelf should be directly under the bottom of the flue, extend the full width of the throat and must be constructed horizontal and not sloped, as its purpose is to stop the down draft.

The space above the shelf is the smoke chamber. The back wall of the chamber is built straight, the side walls are sloped uniformly to the *center* to meet the bottom of the flue lining, and the front wall above the throat is also sloped to the flue lining.

Metal lining plates are available for the smoke chamber and are effective in giving the chamber its proper form and smooth surfaces, as well as simplifying the brick laying.

(e) Fireplace Flue. Relatively high velocities through the throat and flue are desirable and the velocity is affected by both the area of the flue and the height of the chimney. The proper sizes of fireplace flues may be obtained from Table 9-3.

The fireplace should have an independent flue entirely free from other openings or connections, and the first section of flue lining must start at the center line of the fireplace opening. This is important in obtaining a positive and uniform draft over the full width of the fireplace. The flue lining should be supported on at least three sides by a ledge of projecting brick, finishing flush with the inside of the lining.

(f) Fireplace Hearth. The usual practice in hearth construction has been to form an arch of brick from the chimney base to the floor construction and filling over this arch to a level surface to receive the finished hearth, as indicated in Figure 9-3.

Instead of such an arch, a reinforced brick masonry cantilevered slab may be easily constructed. Ribbed metal lath serves as the form and is simply laid in a mortar bed on top of the brick walls of the chimney base and supported at the projecting end by a temporary strip on the floor framing. On this metal lath place a bed of Type A mortar of sufficient depth to cover the ribs and follow at once with the setting of the brick on edge ½ in. apart without mortar. Fill the joints full of cement mortar grout and set the reinforcing bars in place, pressing them down into their proper position approximately 1½ in. below the surface.

The most simple method of constructing this slab is to let it cover the entire area of the chimney base for the width of the hearth. Cut out the lath for the ash chute and basement flues and set the brick to form the proper opening, closing the joints with mortar to hold the grout fill. Flue linings from below should be set to extend above the slab and the brick and grout placed solid around them.

(g) Construction Details. There are two methods of building a fireplace and chimney assembly. One is to complete the fireplace and chimney in one operation as the work progresses. The facing may be omitted until later, in which case suitable ties are built in for properly bonding the facing in place.

The other method is to form a rough opening for the later construction of the fireplace proper. In this case, the end and back walls are built 8 in. thick, a steel lintel is set below the shelf level to carry the front wall above, the back and sides of the smoke chamber are formed and the flue built in. Care must be taken in building the fireplace to finish the work tight to the under side of the previously built chimney to prevent leaks and the possibility of fire hazard.

Several types of steel plate fireplaces are on the market. These are made to combine in one unit the combustion chamber, damper and smoke chamber and need only to be set in place on the hearth and built into the chimney. They are hollow and are provided with openings for circulating the warmed air through ducts and registers.

908. DUTCH OVEN AND OUTDOOR FIREPLACES

(a) A Dutch oven may be desired in connection with a fireplace either for the purpose of completing the appearance of an early kitchen type fireplace or for actual use as an oven.

Included merely as a design feature, the oven will be fitted with a cast iron door and the space thus formed may be used for wood storage, and an open fire box below may be similarly used. The only precaution in this case is to see that the spaces are separated from the fireplace by a brick wall at least 8 in. thick and well built with completely filled joints.

If intended for actual use in baking or roasting foods, the Dutch oven should be carefully designed. The entire interior of the oven should be lined with fire brick and the masonry thickness should be at least 8 in., but greater thickness will increase the heat storing capacity of the oven. The ash drop should be a standard type cast iron unit and may lead either to the side of the fireplace or to an ash pit in the chimney base. The throat should be carefully formed and preferably fitted with a metal damper. A separate flue should be provided for the oven and for the open sizes ordinarily used, an 8 x 8-in. flue lining will be found to be ample. The oven is preheated by fire or hot coals and when the bricks are thoroughly heated, the coals and ashes are removed through the ash drop and the food placed in the oven.

(b) An outdoor fireplace may be intended for ornament and warmth, for cooking, or for both and recognized types have been developed for each class. No attempt will be made to describe the various types because of the great freedom enjoyed in designing these structures. Instead, a few points concerning their construction will be mentioned.

The foundation should, of course, extend below the frost line, although the hearth may be laid on a cinder bed and free of the main structure.

Consideration should be given to the fire resistance of the material used for the interior of the combustion chamber, particularly if local materials are to be used, remembering that fire brick is the most satisfactory for such exposure.

Chimneys should be lined with fireclay flue lining. In northern climates, it is advisable to carry up the corners of the chimney and cover the top with a stone slab to keep out rain and snow and prevent damage from freezing. Flue sizes should be increased because of their reduced height.

Fireplaces built for warmth should follow the same general lines as interior fireplaces, retaining the smoke shelf, but omitting the damper. The throat and flue should be larger and the side splays of the combustion chamber may be omitted.

CHAPTER 10

FIREPROOFING AND FURRING

PART I—FIREPROOFING

1001. GENERAL

Fire prevention engineers, building inspectors, code officials and other experts generally agree that there are four basic requirements of a so-called fireproof building, which may be listed as follows:

(1) It should fully protect the human inmates and provide ample safe means of egress and protection against panic in case of fire.
(2) It should preserve its contents from any ordinary fire originating within or outside the building.
(3) Every fireproof building should be a barrier to conflagration or the spread of fire.
(4) The building, particularly the structural parts thereof, should withstand any fire successfully.

While structural steel is classified as a fire resistive material, it must be protected or insulated against the action of fire when used in fireproof construction. It is well known that unprotected structural steel will increase in strength when subjected to temperatures up to about 600° F. and at approximately 800° F. it will be equal to the normal temperature strength. Even at 1000° F., structural steel may still carry the design loads, however beyond this temperature it rapidly loses strength and is incapable of sustaining its own weight at 1700° F. Maximum temperatures noted in modern conflagrations often reach 1700 to 1800° F. and some fires are known to have gone higher than 2000° F. Accordingly, the whole theory of fireproof building construction must be based upon so designing and building the structures that the above critical temperatures can never occur in the steel; also that the spread of any fire will be so retarded that it may be extinguished before any extensive material damage occurs.

Experience has proven that structural clay tile covering is particularly desirable for the fire protection of structural steel beams, girders and columns, and it has been recognized as a standard fireproofing material for over 50 years. Any protective covering must be durable under all ordinary conditions of wear. A material that will disintegrate under the action of moisture should not be used since condensation may often occur within the walls, particularly near exterior spandrels and around pipe chases and "wet" columns. Covering near the floor may often be subjected to periodic wetting due to cleaning and mopping and the effect of leaks in any area may permanently damage any material that cannot resist the action of moisture and thereby destroy its fire resistive qualities. Fireproofing should be adapted to resist not only the

destructive effect of fire but also the water and action of the fire streams used in extinguishing the fire.

While the amount or thickness of covering is determined by the applicable building code requirements, in general, 2 in. of tile covering is required for beams and girders not supporting walls or other principal building members, and 4 in. for columns in fireproof construction. Specific code requirements are given in Section 1005.

Structural clay tile fireproofing is adaptable to practically all types of floor construction and is frequently used in combination with reinforced concrete systems. With flat and segmental floor arches of hollow tile, the "skewback" units adjacent to the steel beams and girders entirely encase and protect the smaller beams, and "soffit" shapes are provided for the lower flanges. For deeper beams and girders, supplementary shapes and filler units are used below the lower floor surface. Because of its high load-bearing capacity, structural clay tile fireproofing is often used as the bearing support for tile and concrete combination floor systems. This method eliminates the use of continuous shelf angles which are costly.

In addition to its basic function as an effective and permanent fire protection for columns, girders and floor beams of steel skeleton buildings, structural tile fireproofing has many inherent advantages. Several of the most important features are as follows:

Reduces dead load. Tile covering saves from 50 to 75 per cent in weight over concrete covering.

Economical. Tile fireproofing can, in general, be erected in place at nearly the same cost as the form-work required for concrete beam fireproofing.

Speed of erection. Since no forms are required to hold the tile units in place, no period of waiting is required for concrete to set before shores and forms can be removed.

Excellent plastering surface. The tile units provide a very desirable plastering surface. Only two coats of plaster are needed on the tile.

Glazed or unglazed finishes. In many types of buildings, the plaster finish on walls, partitions and columns may be eliminated by the use of tile units with natural smooth unglazed, salt or ceramic glazed finishes. Shapes and sizes are furnished in various thicknesses and percentages of voids to provide any required fire protection.

Load-bearing. Tile fireproofing has the required strength to carry floor loads of ordinary spans with the factor of safety allowed by building codes. Where the spans are long and where there is a heavy load on the floor beam, it is customary to use tile fillers with the cells vertical, which are filled with concrete when the enclosing panel members, ribs and topping are poured in place. This provides a solid monolithic bearing on the lower flange of the beam.

Bracing action. Due to its high compressive strength, tile fireproofing provides a bracing action to resist lateral forces. Beams and girders are strengthened and wind bracing is made more effective.

Barrier against corrosion. When the space between the tile and the steel is filled solidly with mortar, the structural steel is thoroughly protected

against corrosion. Exterior steel members should, therefore, be built in solidly with tile masonry. This also increases the lateral strength and provides additional fire resistance. When the tile fireproofing units are used for supporting floor loads, all spaces between the tile and the steel should be solidly filled with mortar.

1002. STANDARD FIRE TESTS

In order to secure uniformity in construction of buildings of similar character and occupancy and to provide for the safety and welfare of those in or about the building and adjacent structures it is necessary to determine the performance of walls, floors, columns, beams and girders during actual fire exposure. The fire resistive properties of all materials and assemblies must be determined by a standard method of procedure, and expressed in similar terms so that the information may be used by various building and code authorities throughout the country to promote uniformity in requirements.

Specifications for a standard fire test procedure to determine the fire resistance ratings of materials was originally issued as a Tentative Standard of the American Society for Testing Materials in 1917. These specifications have been revised from time to time and are now (1950) designated as Standard Methods of Fire Tests of Building Construction and Materials, E119-. They include a controlled fire endurance test for walls, partitions, columns, floors, roofs, and ceilings, including beams and girders, description of samples, methods of loading, hose stream tests and conditions of acceptance. Results are reported in units of time covering exposure and performance from which actual field exposures can be judged and evaluated.

Building elements, such as walls, columns, floors, beams and girders, must be loaded during the fire endurance and hose stream tests "in a manner to develop theoretically as nearly as practicable, the working stresses in each member contemplated by the designer."

The fire endurance test consists of exposing the test sample to controlled temperatures conforming with the standard time temperature curve (See Fig. 10-1). Points on the curve that determine its character are:

1000° F. (538° C.)	at 5 min.
1300° F. (704° C.)	at 10 min.
1550° F. (843° C.)	at 30 min.
1700° F. (927° C.)	at 1 hr.
1850° F. (1010° C.)	at 2 hr.
2000° F. (1093° C.)	at 4 hr.
2300° F. (1260° C.)	at 8 hr. or over

Tests of Columns. The A.S.T.M. Standard Methods of Fire Tests of Building Construction and Materials were recently amended to provide alternate methods of tests for protected steel columns. The original method provided that the column should be tested under loads "calculated to develop theoretically, as nearly as practicable, the working stresses contemplated by the designer."

Test samples for building columns must be at least 9 ft. long and encased in the protective covering material in accordance with the methods used in typical field practice.

During the fire endurance test the column must be tested in a vertical position, loaded as described above, and exposed to fire on all sides. The

condition of acceptance requires that the column sustain the applied load during the fire endurance test for a period equal to that for which classification is desired. No hose stream tests or maximum allowable temperature rise requirements are included.

The alternate method does not require column loading but provides that a column at least 8 ft. long shall be subjected to a fire test and the temperature of the steel determined at four levels in the height of the column. The test shall be regarded as successful if the transmission of heat through the protection during the period of fire exposure for which clasisfication is desired does not raise the average (arithmetical) temperature of the steel at any one of the four levels above 1000° F. or does not produce a temperature above 1200° F. at any one of the measured points.

Tests of Floors and Roofs, including Beams and Girders. Floor and roof specimens exposed to fire endurance tests should be not less than 180 sq. ft., with neither dimension less than 12 ft. Beams and girders, encased in the material for which the fire resistive properties are to be determined, must

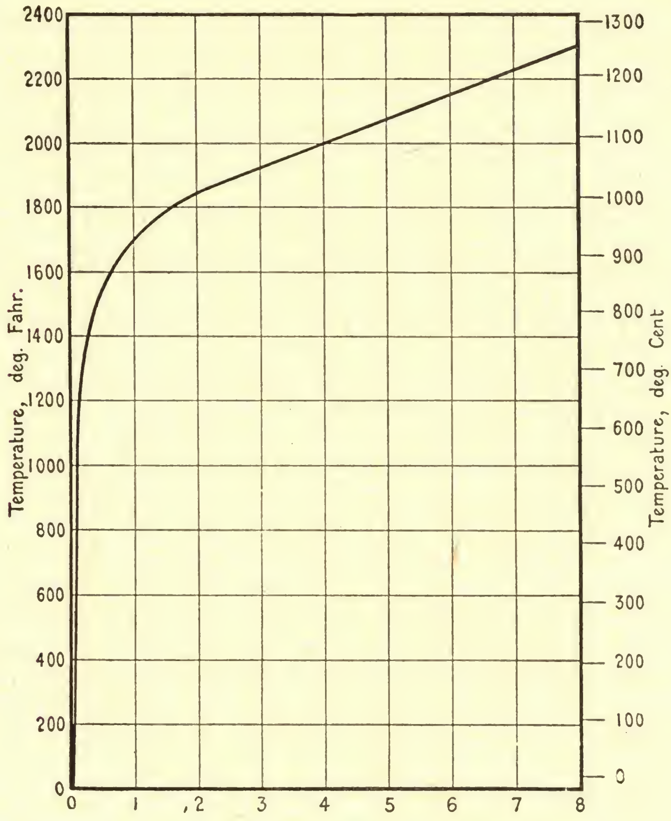


FIG. 10-1

Standard time-temperature curve

lie within the combustion chamber and have a clearance of not less than 8 in. from its walls. The following conditions must be met before the test may be regarded as successful:

(1) "The construction shall have sustained the applied load during the fire endurance test without passage of flame or gases hot enough to ignite cotton waste for a period equal to that for which classification is desired.

(2) "The construction shall have sustained the applied load during the fire and hose stream test, without passage of flame, of gases hot enough to ignite cotton waste, or of the hose stream. After cooling, but within 72 hr. after completion of the hose stream test, floor specimens shall sustain the dead load of the test construction plus twice the superimposed load specified above.

(3) "Transmission of heat through the construction during the fire endurance test shall not have been such as to raise the temperature on its unexposed surface more than 250° F. (139° C.) above its initial temperature."

The hose stream test consists of exposing the specimen to the standard fire exposure for a period equal to one-half of that indicated as the resistance period but not for more than 1 hr., immediately after which the specimen is subjected to the impact, erosion, and cooling effects of a hose stream delivered through a standard fire nozzle at pressures varying from 30 to 45 psi, depending upon the resistance period.

1003. TEST DATA

(a) Fire resistance tests. Fire testing of materials and assemblies under controlled conditions and uniform conditions of acceptance is a development of the last 50 years. Most of the methods of procedure have been in use for at least 25 years with only a few revisions. Tests of floors and partitions were originally established by the New York City Bureau of Buildings in 1896 and were continued in cooperation with Prof. Ira H. Woolson at Columbia University. Some tests on columns were made even earlier, however, it was not until 1918 that comprehensive data became available.

Preliminary work on an extensive test program was started in 1910 by the Associated Factory Mutual Fire Insurance Companies and Underwriters' Laboratories with the cooperation of the National Bureau of Standards. After the final schedule of tests was adopted, the preparatory work of erecting and covering the test columns required a full year and was completed in May 1917.

These tests were originally reported jointly by the sponsors, and later by the Bureau of Standards in Technologic Paper No. 184, April 21, 1921, "Fire Tests of Building Columns" by S. H. Inberg and H. K. Griffin of the National Bureau of Standards, W. C. Robinson of the Underwriters' Laboratories and R. E. Wilson of the Associated Factory Mutual Fire Insurance Companies.

A total of 106 columns were tested, of which 91 were fire tests and 15 fire and water tests. In addition to the tests on columns protected with structural hollow clay tile, the complete series included tests on columns covered with concrete, gypsum block, plaster on metal lath, reinforced concrete columns and unprotected steel, cast-iron and timber columns.

Tests with clay tile covering included five kinds of tile from as many producing regions. There were two varieties of surface clay tile, one of shale and two of semifire clay. Fire tests were conducted on a total of 20 columns with either 2-in. or 4-in. tile covering. Several columns were included with

TABLE 10-1

ULTIMATE FIRE RESISTANCE PERIODS OF COLUMN FIREPROOFING

Compiled from NBS Technologic Paper No. 184

Type of Column	Protective Covering				Ultimate Fire Resistance Period Hr. Min.
	Material	Kind	Nominal Thickness (in.)	Description	
Steel①	None	.....	.....		0—15¼
Cast iron②	None	.....	.....		0—37
Steel	Brick	Chicago Common	2¼	Brick fill—brick covering laid on edge...	1—40¾
Steel	Brick	Chicago Common	3¾	Brick fill—brick covering laid flat......	7—13¼
Steel③	Hollow Tile	Surface Clay	2	Concrete fill—no ties..	1—32½
Steel④	Hollow Tile	Semifire Clay	2	Concrete fill—outside wire ties...........	3—24
Steel	Hollow Tile	Semifire Clay	2	No filling—outside wire ties...........	0—50¼
Steel	Hollow Tile	Shale & Semifire Clay	2	Concrete fill—wire mesh in joints—¾ in. plaster finish....	4—25½
Steel	Hollow Tile	Shale	2	Cinder concrete fill—outside wire ties....	1—40
Steel④	Hollow Tile	Surface Clay	4	Concrete fill—outside wire ties	2—52
Steel	Hollow Tile	Semifire Clay	4	Concrete fill—wire mesh in joints......	3—33½
Steel	Hollow Tile	Surface& Semifire Clay	4	Concrete fill—wire mesh in joints. ⅝-in. plaster finish....	4—42¼
Steel	Hollow Tile	Surface Clay	Two 2	Hollow tile fill—outside wire ties.......	1—33¾
Steel	Hollow Tile	Surface Clay	Two 2	Hollow tile fill—wire mesh in joints......	4—35¾
Steel	Hollow Tile	Shale	4	Cinder concrete fill—outside wire ties....	1—22¼
Steel	Solid Gypsum③	.....	2	Solid gypsum fill—metal ties or mesh in joints...........	2—28¾
Steel	Solid Gypsum	.....	4	Hollow gypsum fill—metal ties in joints..	4—43¼
Steel	Solid Gypsum③	.....	4	Solid gypsum fill—wire mesh in joints..	5—58
Steel	Cement Plaster	.....	1	Portland cement plaster on metal lath—1 layer.............	1—07¾
Steel	Cement Plaster	.....	2	Portland cement plaster on metal lath—2 layers...........	2—52

① Average of 8 tests. ② Average of 4 tests. ③ Average of 2 tests. ④ Average of 3 tests.

coverings consisting of two 2-in. layers of tile. Fire and water tests were also made on three columns protected with clay tile covering in order to determine the effect on coverings and columns of the impact and sudden cooling produced by hose streams applied to them when in a highly heated condition.

A summary of the ultimate fire resistance periods for columns with various types of protective coverings and unprotected sections as compiled from T.P. No. 184 is given in Table 10-1.

It should be noted that the steel columns included various fabricated sections which are no longer in popular usage. It is reasonable to assume that the present heavy H sections would produce considerably higher resistance periods than obtained from members containing ¼-in. plates and lattice bars particularly when they are nearly adjacent to the outside protective covering.

As indicated in Table 10-1, outside wire ties were used in some cases to support the concrete fill which was generally poured after the tile covering was placed. Since these ties were only approximately ⅛ in. in diameter and directly exposed to the high test temperatures, it is reasonable to assume that they could be of little assistance in securing the position of any covering after the start of the test. Where high fire resistance periods are required, wire mesh may be used in the horizonal joints or "U" shaped clips extending into the cells of adjacent units.

(b) Burn-out tests. Investigations conducted at the National Bureau of Standards, under the direction of S. H. Ingberg, indicate that fire severity in fire resistive buildings may be related to the average weight of combustible contents per square foot of floor and expressed in terms of exposure equivalent to that in the standard fire test.

Burn-out tests were performed in fireproof structures with various concentrations of combustible materials having a calorific value in the range of wood and paper (7000 to 8000 Btu per lb.) and assembled to represent building occupancies. These tests indicate that the following relationship between the amount of combustibles and fire severity, as reported in the National Bureau of Standards Building Materials and Structures Report BMS92, will approximately apply:

RELATION OF AMOUNT OF COMBUSTIBLES TO FIRE SEVERITY

Average weight of combustibles, psf. of floor area	Fire Severity (hr.)	Average weight of combustibles, psf. of floor area	Fire Severity (hr.)
5	½	30	3
7½	¾	40	4½
10	1	50	6
15	1½	60	7½
20	2		

Since the above classification is based upon the use of wood furniture and shelving, a corrected effective weight of combustibles should be used where the combustibles are stored in steel or equivalent incombustible containers. Approximate percentages considered sufficiently accurate to use are given as follows:

EFFECTIVE COMBUSTIBLE CONTENTS OF STEEL CONTAINERS

Type of Container	Part of combustible in containers		
	Less than one-half Per cent	One-half to three-fourths Per cent	More than three-fourths Per cent
Backed and partition shelving	75	75	75
Shelving with doors and transfer cases	60	50	25
Filing cabinets and desks	40	20	10
Safes and cabinets of 1 hr. or more fire resistance rating	0	0	0

1004. FIRE RESISTANCE RATINGS

Fire ratings of clay tile fireproofing based on the results of study and research by the Building Code Committee of the U. S. Department of Commerce are contained in BH No. 14 "Recommended Minimum Requirements for Fire Resistance of Buildings." These ratings have been determined from tests conducted at the National Bureau of Standards and other laboratories as described in Section 1003, comparisons with other tests, performance in actual fires and the collective experience of many building and fire authorities. The following recommendations, contained in this report, have been generally accepted as established standards.

(a) Steel beams, girders and trusses. Structural clay fireproofing is required to cover lower flanges and portions of webs or members, not protected by arches or floor slabs, as follows:

Four-hour rating: Three in. or more of hollow clay tile; well anchored or bonded and plastered with not less than ½ in. of gypsum or portland cement plaster.

Three-hour rating: The above or 2 in. or more of hollow clay tile; well anchored or bonded, and plastered as above.

Two and one-half-hour rating: Any of the above, or 1½ in. of burnt clay or shale—total solid thickness.

For lower ratings any of the above coverings may be used, without plaster if desired. Typical covering for ratings up to and including 2 hr. consists of 2-in. hollow tile for flanges and 3- or 4-in. hollow tile for webs.

The 2½-hr. rating, without plaster, may require unscored units or a heavier shell type in order to obtain the 1½-in. minimum solid thickness. Standard scored units, plastered, will meet the requirements for the 2½- or 3-hr. rating as described.

(b) Steel columns. Structural clay tile column covering is required to protect the webs and flanges of these supporting steel members as follows:

Four-hour rating:

(1) Two 2-in. layers or more hollow clay tile; hollow clay tile fill in the reentrant spaces, metal mesh in the horizontal joints, or

(2) Two in. or more hollow clay tile; limestone concrete fill, wire mesh in horizontal joints, plastered with at least ¾-in. gypsum plaster, or

(3) Four in. or more hollow clay tile; limestone concrete fill, wire mesh in horizontal joints, plastered with at least ⅝-in. lime plaster, or

(4) Two in. or more hollow clay tile; shells and webs at least ¾-in. thick, concrete fill, well anchored or bonded, plastered with at least ½-in. gypsum or portland cement plaster, or

(5) Four in. or more hollow clay tile; concrete fill or fill of burnt clay or shale, well anchored or bonded, plastered with at least ½-in. gypsum or portland cement plaster.

Three-hour rating: Any of the above or,

(1) Two in. or more hollow clay tile; concrete fill or fill of burnt clay or shale, extending at least ¾-in. outside flanges, well anchored or bonded.

Two-hour rating: Any of the above, or

(1) Two in. or more hollow clay tile; well anchored or bonded, plastered or unplastered.

One-hour rating: Any of the above, or

(1) Two in. or more hollow clay tile; well anchored or bonded, no fill.

1005. FIRE RESISTIVE REQUIREMENTS

(a) Building Code. Fire resistive requirements in building codes refer in general to the construction of walls, floors, and partitions and the protection of structural members including beams, girders, trusses and columns. These requirements are usually designated in terms of the ultimate fire resistance period which each building element must withstand. It is noted, however, that many codes express the requirements in terms of materials and designated dimensions. This information is also included in the appendix of some recent codes with ratings tabulated for various details of construction and protective coverings or fireproofing materials, as based on actual performance records and standard fire tests.

Fire resistive requirements are classified in accordance with various types of construction which are frequently designated as follows:

Type I—Fireproof (Fully protected)
II—Semi-fireproof (Protected)
III—Heavy Timber
IV—Ordinary (Masonry wall and joist)
V—Light non-combustible
VI—Frame
VII—Unprotected metal

The required fire resistive periods for beams, girders and columns of the principal types of construction listed above are contained in the Department of Commerce report BH No. 14 "Recommended Minimum Requirements for Fire Resistance in Buildings." In general, a 4-hr. fire resistance period is required for columns, trusses and girders which support walls in Type I, fireproof construction, and 2½ hr. for beams and other girders. For Type II, semifireproof or protected construction, a 3-hr. fire resistance period is required for columns and girders supporting walls; 2 hr. for columns and girders not otherwise specified and 1½ hr. for other floor beams and girders.

(b) Material. All structural clay tile used for column covering and fireproofing should conform in quality to the Standard Specifications for Structural Clay Non-Load-Bearing Tile, A.S.T.M. Designation C56. If intended for use in load-bearing masonry, they should conform to the physical requirements of A.S.T.M. Specification C34 for Load-Bearing Wall Tile.

1006. CONSTRUCTION METHODS

(a) **Beam and Girder Covering.** Structural clay tile used for fireproofing the lower flanges of steel beams and girders are known as "clip" tile, "angle" tile and "soffit" tile. These units and methods of application are illustrated in Fig. 10-2 and 10-3. Frequently for smaller beams, only the clip tile are required; however, when the beams extend below the lower floor surface, the web must be protected with filler tile of the required thickness, generally 3- or 4-in. tile unless otherwise specified. At spandrel beams and loose steel lintels over window heads and other openings, a single clip tile will provide a good return for plastering and thoroughly fireproof the flange section.

Filler units may vary in height from 2¼ to 12 in., in 1-in. increments as required to fit the opening between the top of the clip or angle tile and the bottom of the floor slab, or top flange of the beam. In many cases only one filler unit is required or a combination of two standard units may exactly fill the space. For deep beams and girders, one or more courses of typical 12 x 12-in. face size filler units are used which may exactly work up to the proper height but usually will require a supplementary slab or smaller filler unit at the top. Filler tile may be set with the cells vertical or horizontal depending somewhat on the space to be covered, but particularly on the type of floor system. Half lengths of filler or clip tile are used at the ends of alternate courses to provide staggered end joints, which should overlap the subjacent units at least 3 in.

When combination tile and reinforced concrete rib or slab floors are used it may be desirable to permit the concrete to fill the cells of the tile to provide direct bearing on the beam flanges. This is required only for heavy loads as it is usually desirable to reduce the weight and lower the cost by using slabs or horizontal cell units at the top course to prevent excess concrete from entering.

With tile arch or other structural tile systems, the floors may be supported directly on the tile covering; however, when used in this capacity, load-bearing filler tile are required and the space between the web and tile should be completely filled with mortar. It should be noted, too, that some building codes require that the space between the web and tile be filled with mortar where additional fire protection is required and also to eliminate the possibility of corrosion.

Double beams may be protected on the bottom by special long clip or "shoe" tile, however the soffits are usually covered with standard 2-in. thick rectangular tile of the proper length, supported on metal clamps or hangers which are usually made from No. 16 gauge strap iron, ⅞ to 1 in. in width. For girders or double beams having flanges over 14 in. in width, the soffit tile should be 3 in. in thickness. With smaller soffits only one metal clamp is required on each side placed at diagonally opposite corners, while two clamps should be used on each side for larger sizes over 12 in. in length. After the soffits are in place, angle tile are mortared over the ends with sufficient mortar to enter the open cells of the soffit tile to provide a secure reinforced corner. Since no forms are needed to hold tile fireproofing in place, there is, of course, no period of waiting for the work to proceed as is required for concrete before shores and forms can be removed. Tile units for girder covering are usually of the proper thickness to fill the entire space into the web. In some cases, two thicknesses of tile are specified for additional protection.

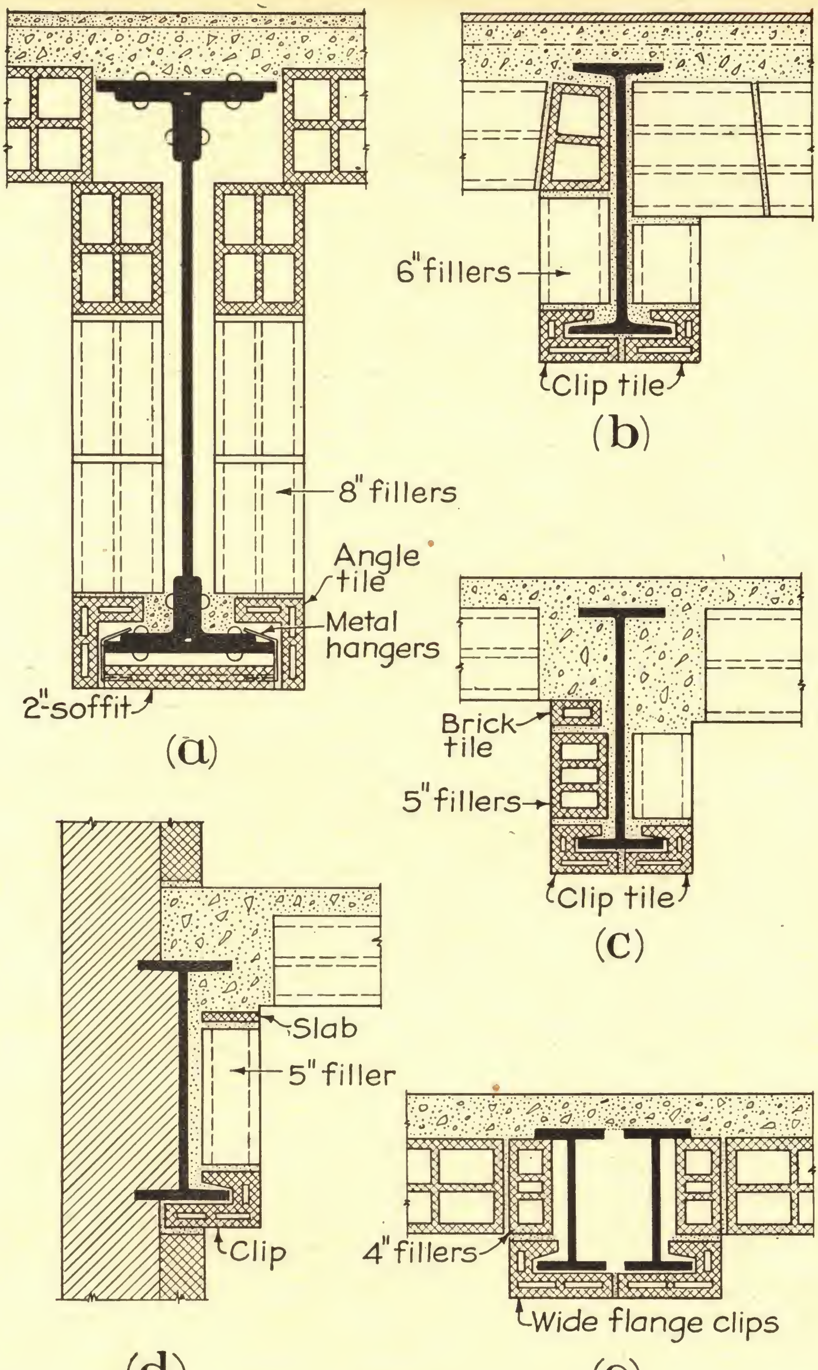


FIG. 10-2
Typical structural clay tile girder fireproofing details

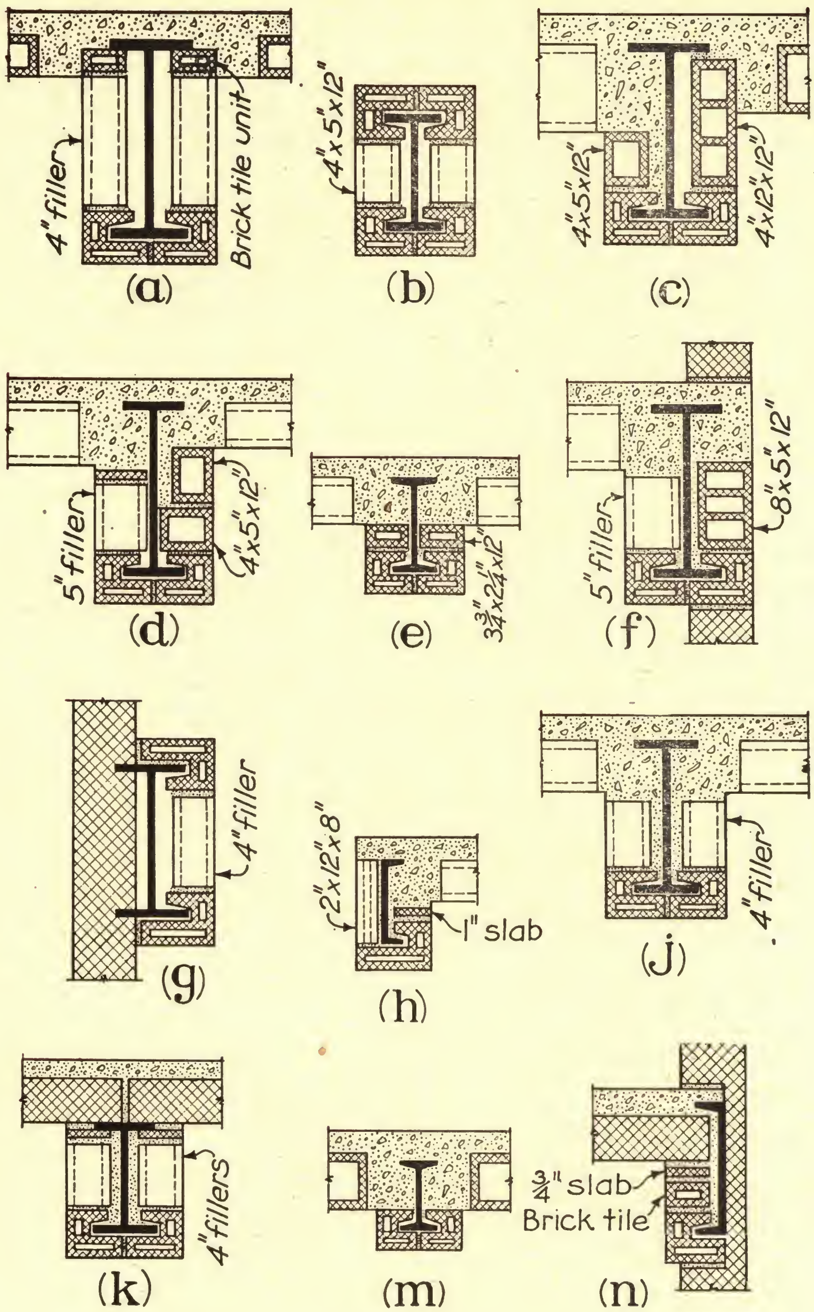


FIG. 10-3

Typical structural clay tile beam and girder fireproofing details

With flat arch construction, girder covering may be set when the floor units are placed, or after, as determined by the size of the supporting members, thickness of floor, and method and direction of support. It is important that the builder determine the proper and most economical method of erection.

While tile fireproofing has always been used with flat and segmental floor arch construction, many designers and builders take advantage of its flexibility and economy with all forms of concrete and metal floor systems. Tile fireproofing with concrete slab and joist systems provide savings in cost and reduction in dead loads up to 60 per cent compared with concrete fireproofing. With concrete floors requiring form work, the beams are usually covered with tile after the floor is in place, thus permitting the use of the bottom flange to support the floor forms.

Structural steel supporting members, for metal joist and thin concrete slab floor systems, should be covered entirely with tile fireproofing up to the underside of the slab. Buildings constructed of heavy slow-burning timber supported on a steel frame can be made much more secure if the supporting members are protected with tile fireproofing.

(b) Column Covering. In accordance with building code requirements for fire resistance, the reentrant spaces of steel columns are generally filled with mortar, brick, structural tile or concrete for additional security against fire and to prevent the possibility of corrosion.

When tile fillers are used for web covering, the proper size of unit should be selected from the various partition, wall or building tile shapes to fill the reentrant space, allowing for at least ½ in. of mortar against the steel. If the reentrant spaces are filled with concrete or mortar, no formwork is required since the tile covering is utilized in this capacity. Tile units for covering are placed and allowed to set before the fill is poured so that there will be sufficient strength to resist the side pressure. Where plaster finish is intended on the columns, the tile should be banded with No. 12 steel wire placed tightly around the outside of each course to provide support for the fill. With glazed or unglazed facing tile, the concrete or mortar fill may proceed as the units are laid, however this is advisable only on larger jobs where a mason may work on a number of columns, laying 2 or 3 courses or lifts of 10 to 12 in., and allowing the mortar to harden before the fill is made. Where it is desired to fill the columns with concrete after the covering is in place, wire bands may be placed around the facing tile units, however the units must be protected from injury.

As indicated in Section 1004, when a high fire resistive rating is designated, wire mesh may be required in the bed joints, or interior metal clamps to hold the units together. The mesh may consist of strips of woven wire or "hardware-cloth" of ½-in. mesh, approximately ½ in. less in width than the tile units, placed in the horizontal joints and lapped at corners and spaced from 1½ to 2 ft. apart vertically. Clamps or clips of No. 18 gauge "U"-shaped strap iron, approximately ¾ in. in width, are recommended as an optional method of support. They are slipped down in the cells of adjacent units as each course is laid.

Typical rectangular units in the 12 x 12-in. face size in 2-, 3- or 4-in. nominal thicknesses, as required, are generally used where plastered finishes are specified. These units are economical and are universally available. A double covering of 2-in. tile is generally recommended where the fire

hazard is great and for important columns that carry heavy truss, wall or girder loads. Heavy-duty load-bearing units, both rectangular and segmental, are also available in most localities with plaster-base or exposed-wall finishes for protective coverings or complete tile columns. When the columns are covered with glazed or unglazed facing tile, rounded or bullnose corner units (1-in. radius), are generally specified. In working areas subject to trucking, wheeling, or handling of packages, the lower portion of all columns, plastered or unplastered, should be protected with steel angles at the corners, or a complete covering of No. 16 gauge steel embedded in cement mortar may be specified for the lower 5 ft.

All column covering should start directly on the structural floor and extend to the fireproof floor above. It should be designed to properly fit the column, with at least ½-in. clearance between the steel and the tile. This space is generally filled by cement parging on the steel or by back-mortaring the units or slushing as the tile are laid.

No piping should be enclosed in column fireproofing, however rigid electrical conduit may be embedded into the web space before the column covering is placed. These conduits should be grouted in solid with at least 3 in. of solid material between the structural steel and the conduit.

(c) Recommended Mortars. For ordinary installations, structural clay tile used for beams, girder and column covering may be laid in cement-lime mortar conforming to the requirements of Type B as described in Chapter 5; or a 1:3 gypsum-sand mortar may be used if desired. Where tile fireproofing or column covering is used in a load-bearing capacity, it should be laid in cement mortar conforming to Type A of the above specification. In laying the tile, all bed and end joints and reentrant spaces in the flange units should be well filled with mortar when they are placed.

1007. SHAPE AND CONSTRUCTION DETAILS

Typical construction details for column fireproofing are shown in Fig. 10-4. Supplementary shapes used in beam and girder covering consist of solid slabs, ⅝ to 1 in. thick, 12 in. long and 4, 5 or 6 in. wide; also the standard "brick-tile", similar in cross-sectional area to ordinary building brick, 12 in. long and cored with one or two cells in the nominal 4-in. width. The latter unit is also frequently used in wall construction as a backing unit for brick headers.

Shoe or clip tile and angle tile are furnished in the 12-in. length, and a percentage of half lengths are shipped with each order for bonding purposes. Standard filler units are also 12 in. long but are furnished in various cuts from 3 to 10 in. in 1-in. increments, as required, for use in the end position with cells vertical. When used in the horizontal position, only the standard 12-in. length and a percentage of half lengths are required. As the material is received at the job, it is very important that all sizes of clip, angle and filler tile be piled in separate groups to facilitate handling and stocking during construction.

Tile beam and girder covering is sold on a basis of the square footage of the actual outside surface of the tile surrounding the beam. Estimates can be made of the approximate amount of tile required by taking the linear distance in feet around A+B+C as shown in Fig. 10-5(a), or A+B+C+D, as shown in Fig. 10-5(b), and multiplying this sum by the length of the beam

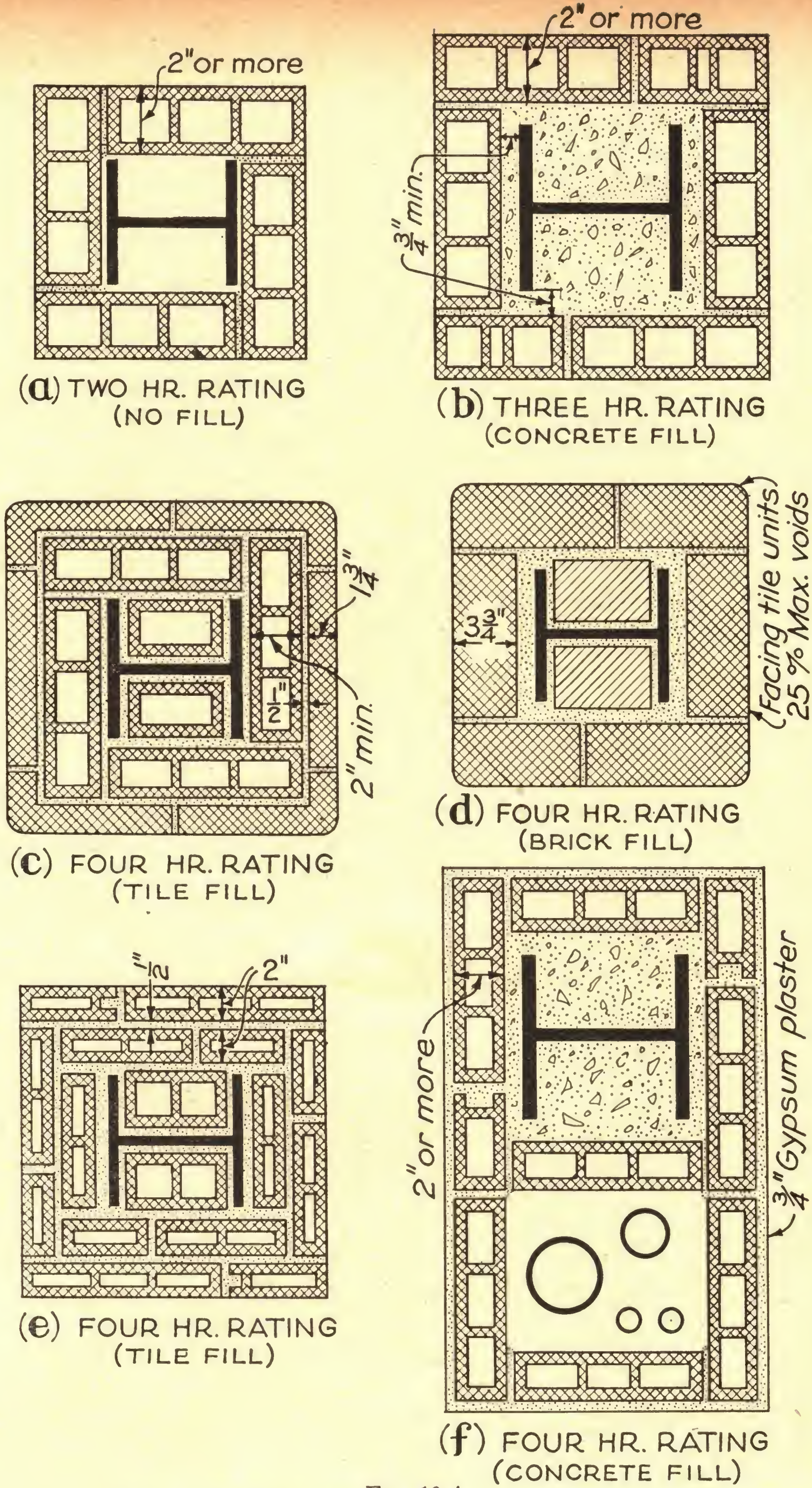


Fig. 10-4

Typical structural clay tile column fireproofing details

in feet. For ordinary covering, using 3- or 4-in. fillers, the weight of tile fireproofing will be approximately 20 psf of superficial surface. However, *if full-width web covering is required with additional mortar at webs, or* concrete filling is used in connection with concrete floors, the additional weight must be computed.

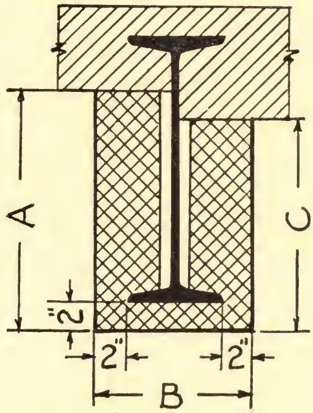


FIG. 10-5(a)

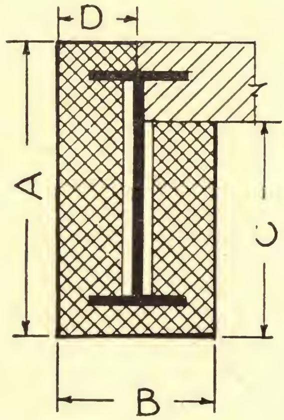


FIG. 10-5(b)

Method of estimating

Dimensions of clip and angle tile as produced by the various manufacturers may vary slightly, however they conform essentially to the tabulation of sizes shown in Table 10-2.

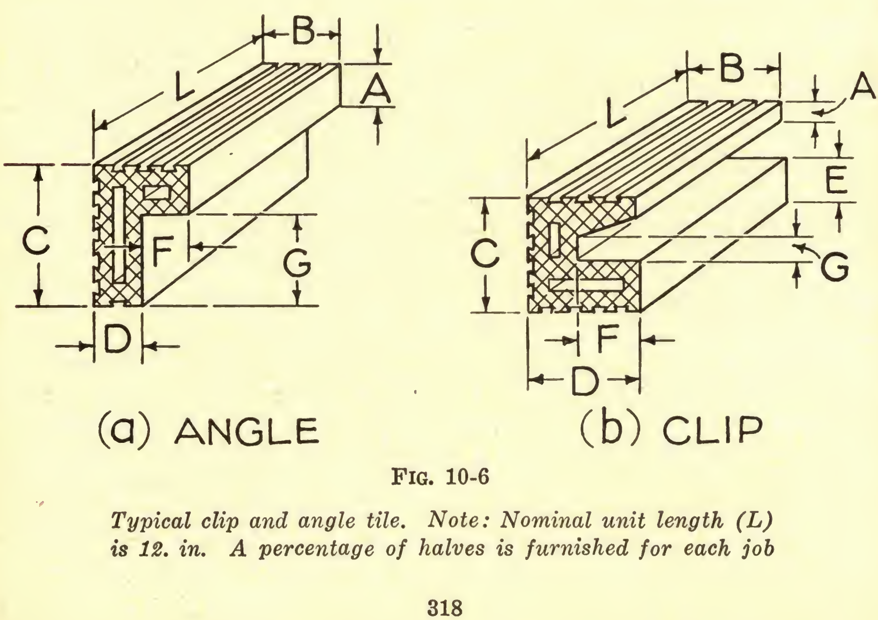


FIG. 10-6

Typical clip and angle tile. Note: Nominal unit length (L) is 12. in. A percentage of halves is furnished for each job

TABLE 10-2

TYPICAL CLIP AND ANGLE TILE SIZES

Unit No.	Sq. ft. outside measure	Weight per piece lb.	A	B	C	D	E	F	G
G20	.65	13	¾	3⅜	3⅜	3¾	2	2	¾
G25	.70	14	¾	3⅞	4	4½	2	2½	13/16
G30	.75	15	⅞	4¼	4¼	4¾	2	3	⅞
G35	.80	16	¾	4¾	4¼	5½	2	3½	1
G40	.85	17	¾	4¾	4¼	6	2	4	1
G45	.90	18	¾	4¾	4¼	6½	2	4½	1
G46	.95	19	¾	4¾	4¾	6⅝	2	4⅝	1½
G50	.95	19	¾	4¾	4¼	7	2	5	1
G55	1.00	20	¾	4¾	4½	7½	2	5½	1¼
G60	1.05	21	1	5½	4⅝	8	2	6	1⅜
G61	1.05	21	1	4½	4⅝	8	2	6	1⅜
G70	1.16	23	1	6	4⅞	9	2	7	1½
G71	1.16	23	1	4½	4⅞	9	2	7	1½
G75	1.33	29	2	7½	6⅜	9½	2	7½	2⅜
G80	1.40	32	2	8	6⅞	10	2	8	2⅞
L23	.60	12	2	4	5	2	...	2	3
L26	.90	18	2	4	8½	2	...	2	6½
L43	.65	13	2	6	5	2	...	4	3
L46	.95	19	2	6	8½	2	...	4	6½

The following procedure is recommended for the selection of the proper sizes of clip and angle tile:

(1) Obtain the width of the beam flange, either by field measurement, or from the structural steel handbook.

(2) From Table 10-2, select the clip tile having the "F" dimension (see Fig. 10-6) nearest to ½ the width of flange.

(3) Order two pieces of clip tile for each linear foot of beam, when the flange is covered on both sides.
Example: Beam having a flange width of 6¼ in. will require a G30 clip, since ½ of 6¼ in. is 3⅛ in., and the G30 has an "F" dimension of 3 in.

For some of the especially thick-flange beams, it is advisable to check the "G" dimension of the tile with the thickness of the nose of the beam flange.

Angle tile should be selected so that the "G" and "F" legs are long enough to cover the special condition for which it is needed.

Part II—Furring

1008. DESCRIPTION

The term "furring" is used to describe a method of construction frequently used for the interior surface finish of masonry and concrete walls.

It refers particularly to the separation of the exposed finish with an air space between the structural wall and the finishing material, or, in some cases, to a cored material applied directly to the structural wall as a veneer. Structural clay tile is extensively used for both types of furring, with units designed for the direct application of plaster, if desired, or for an exposed tile surface finish.

Split furring tile with "plaster-base" or "exposed-wall" finishes is furnished in a nominal 12 x 12-in. face size, generally 2 in. thick or 1½ in. on special order. These units are made by "kerfing" full size partition tile when manufactured, so that a single unit may be split longitudinally into two half-units with projecting lugs or open backs as shown in Fig. 10-7. Full thickness units with solid backs are furnished in nominal 2-, 3- and 4-in. thicknesses in the partition size (12 x 12-in. face) and in 2- and 4-in thicknesses in the various sizes of facing tile.

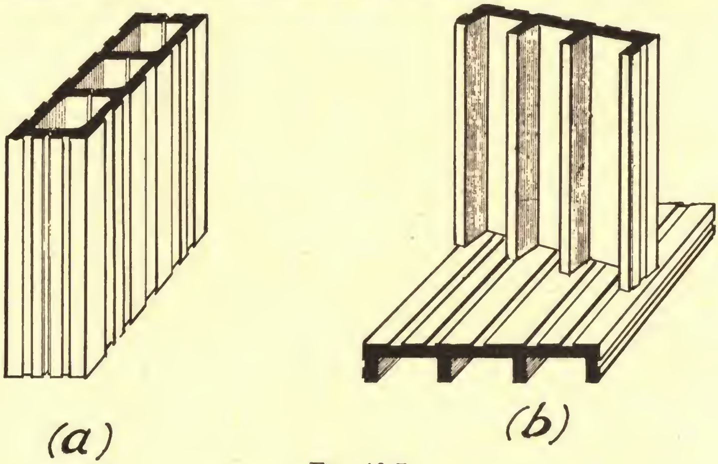


FIG. 10-7

Kerfed unit (a) for split furring (b)

In many types of buildings where solid masonry walls of brick and stone or concrete walls are specified, it is a standard requirement to furr the interior surface of exterior walls with structural clay tile units to prevent dampness from reaching the interior surface by capillarity and thus marring the plaster or interior finish of the building. In addition, the air space between the wall and the furring units, and, in the case of full units, the tile itself, or both, will provide a greatly increased insulating value and reduce the possibility of condensation.

When 12-in. composite walls are specified, with brick facing on the exterior backed with hollow tile, the plaster finish is generally applied directly to the wall surface.

Interior plaster finish on walls and partitions which requires constant maintenance and painting has been replaced, in many types of buildings, with glazed and unglazed facing tile. These units are often used as furring, but are generally bonded with and included as a portion of the structural wall due to their high load-bearing capacity. Furring with facing tile units, 2-in. nominal thickness, for walls and partitions is often recommended when the material must be shipped from some distance, however,

it is generally most economical to use the 4-in. nominal thickness units to replace the inner wythe of the structural masonry wall. With this construction, typical load-bearing tile is used for the inner core bonded with either 6-in. or 8-in. thickness facing tile.

Structural tile for furring should comply with the A.S.T.M. Standard Specifications for Structural Clay Non-Load-Bearing Tile, C56—.

Faces of split furring and hollow tile should be of the plaster-base or exposed-wall finish, as specified.

1009. TYPES OF FURRING

(a) Attached. The direct application of structural tile units to the exterior wall surface and fastened or anchored to the wall with wires, mesh, nails or other metal devices, is described as "attached" furring.

Split furring is usually 2 in. in nominal thickness and is always applied directly to the wall without mortar on the back of the ribs to avoid solid contact. This provides an uninterrupted air space. Hollow or cored structural units when used as attached furring may be 2, 3 or 4 in. in thickness, however the 2-in. units, often designated by the term "soaps," are generally used. Since these units have one or more air cells through the thickness, the space between the units and the wall may be filled with mortar, if desired for greater rigidity or where exterior wall parging is specified.

In some cases, tile furring units may be applied directly to the wall without metal anchors by utilizing the high adhesive bond obtained by filling the back space with cement grout. Experiments conducted on reinforced masonry indicate that the adhesion of cement grout to natural masonry surfaces is very effective. Recent developments in waterproof adhesive cements indicate that metal anchors may also be omitted for certain types of construction when using this method of attachment.

(b) Free-Standing. It is often desirable, because of wall offsets and recesses, pipe spaces, etc., to place the tile furring several inches from the wall and completely unattached. This is described as "free-standing" furring. In accordance with height and length limitations and tile thickness, it may be necessary to brace the furring at specified intervals by the use of drive anchors, or short tile sections may be used between the wall and the furring to replace the anchors.

Free-standing furring is generally 4-in. nominal thickness for both structural and facing tile. In some cases, 3-in. structural tile is used, or, if desired, 2-in. thick hollow tile under certain conditions as listed below. It is more economical, however, to use nominal 3-in. or 4-in. tile which is easier to set and bracing is seldom required. Height and length limitations for the various sizes of free-standing furring tile installations should not exceed the following:

Nominal tile thickness (in.)	Maximum unsupported height (ft.)
2	9①
3	12
4	15
6	20
8	25

① Not over 6 ft. in length.

1010. CONSTRUCTION METHODS

(a) Metal Ties and Anchors. Where tile furring is set against brick or stone masonry walls or composite walls of solid masonry units, it should be properly fastened or attached to the wall in accordance with the requirements shown in Table 10-3.

TABLE 10-3

FURRING TILE, HEIGHT AND LENGTH LIMITATIONS AND SPACING OF METAL TIES AND ANCHORS

Type and Thickness (in.)	Maximum Allowable Spacing		
	No. ties required	24 in. Vertically and 24 in. Horizontally (ft.)	16 in. Vertically and 24 in. Horizontally (ft.)
2 in. Split........	..	Up to 14	From 14 to 35
2 in. Hollow......	9①	From 9 to 14	From 14 to 35
3 in. Hollow......	12	From 12 to 18	From 18 to 35
4 in. Hollow......	15	From 15 to 22	From 22 to 35

① Not over 6 ft. in length.

1. Nailing. Typical 12 x 12-in. face size structural and split furring tile is frequently attached to the walls by driving 10d nails into the masonry joints and clinching the heads of the nails down into the cells of the tile or over the ends of split tile. If a rich cement mortar has been used for laying up the masonry wall, it may be somewhat difficult to drive ordinary nails into the joints, particularly if there has been any delay in placing the furring. In this case a special short heavy nail or other metal device designed for this purpose, may have to be substituted.

2. Wire ties. It is frequently advisable to place heavy wire ties into the bed joints as the wall masonry is erected. These ties should be not less than No. 11 gauge and bent down into the cells or over the tile; or not less than No. 13 gauge wire doubled and looped through the mortar bed to form a secure bond.

3. Corrugated or crimped metal ties. The most common type of metal tie used in furring or veneering masonry walls is the galvanized corrugated or crimped type. These ties should be at least ⅞ in. wide and not lighter than No. 22 gauge.

4. Wire-mesh ties. Where wire netting or hardware cloth ties are specified they should be at least 4-in. wide strips of ½-in. mesh No. 20 gauge galvanized wire fabric. These ties should extend at least 3 in. into the masonry wall and to within ½ in. of the face of the veneer or furring.

5. Anchors. Furring is attached to concrete by the use of dovetail anchors which are inserted in metal slots imbedded in the concrete. These anchors should be at least ⅞ in. wide and not lighter than No. 16 gauge. Wire ties may be used in place of the dovetail anchors. Wire ties are hooked into the slots or inserts and should be not lighter than No. 9 gauge.

(b) Mortar. Recommended mortars for clay tile furring should be Type B or Type C, as described in Chapter 5. In general, Type B, cement-lime mortar, is used for exposed masonry, while Type C mortar, containing

a higher percentage of lime, is frequently specified where the plaster finish is desired.

(c) General Recommendations:

1. Furring tile should start at the structural slab or footing and extend to the ceiling above. Where suspended ceilings are used, it should extend at least 2 in. above the ceiling level but not above the lath that contacts the bottom of joist construction. Free-standing furring around pipes, shafts, etc., should extend to the ceiling slab.

2. Tile units should be bonded each course at corners and intersections and vertical joints should be broken at least 3 in.

3. Where tile furring occurs over waterproofing, free-standing construction should be used with no ties or anchors extending through the waterproofing.

4. Furring enclosing pipe spaces should be built after the pipes are in place and properly tested. It should not be bonded to other masonry but anchored thereto only with metal ties.

5. Structural tile furring should be built plumb to lines and laid in full beds of mortar. It should be used to cover all wall chases, cavities, etc., and to bring the face of the wall to a proper line for plastering or for an even and uniform tile surface.

(d) Furred plaster. Furring of 6- or 8-in. thickness masonry walls of brick or tile with 1 x 2-in. or 2 x 2-in. wood nailing strips or metal channels, etc., for the application of lath, insulation or plaster board and plaster is generally recommended for residential construction in localities subject to cold weather and high humidity conditions. Construction methods for furred plaster are discussed in Chapter 11.

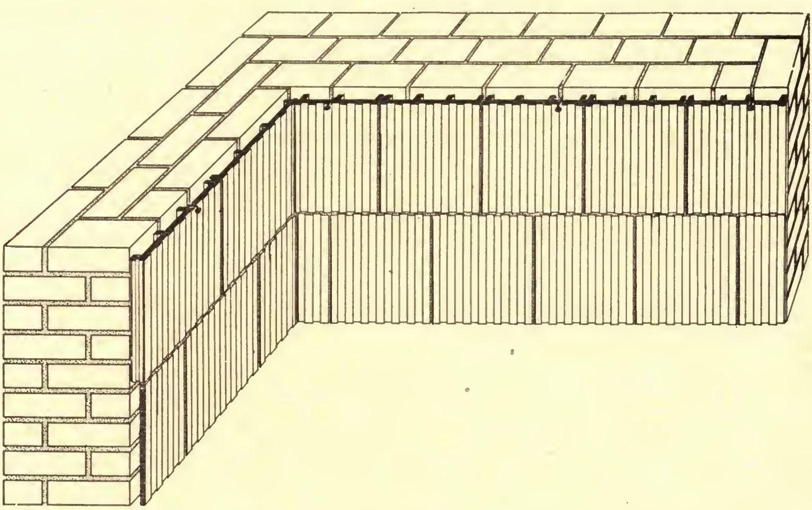


FIG. 10-8

Split furring tile showing typical method of application

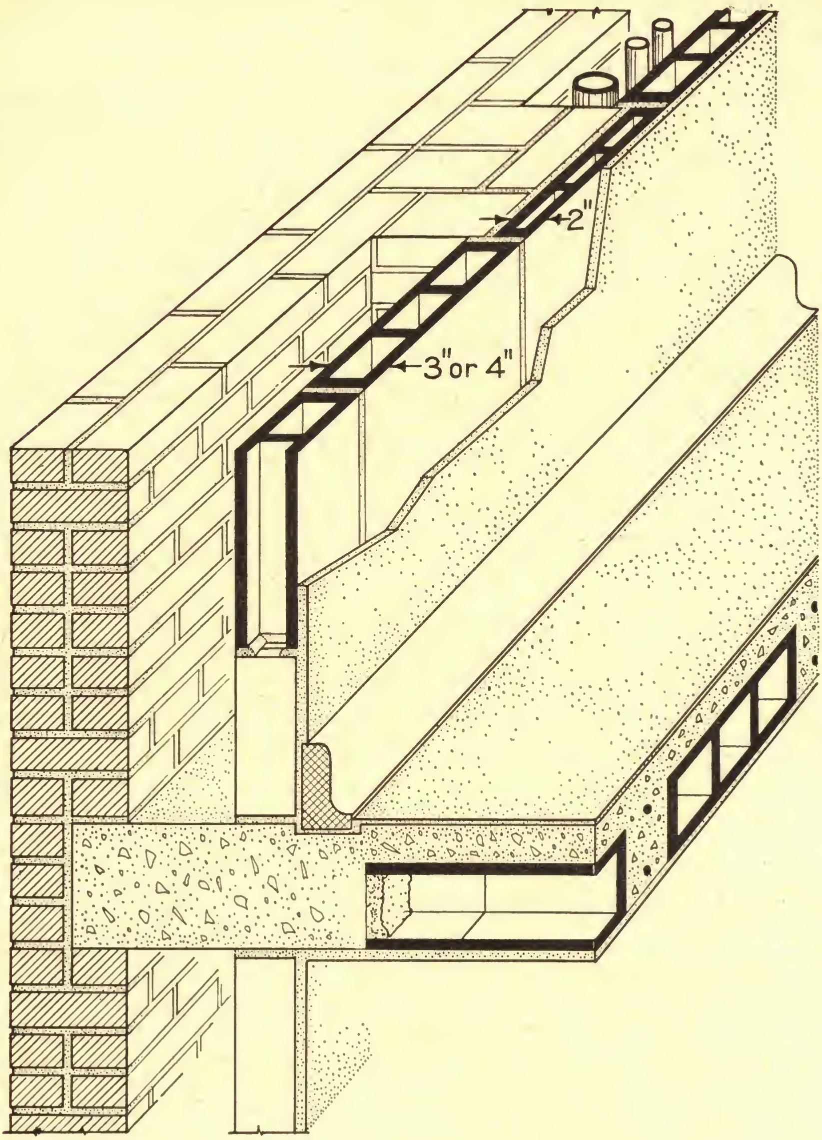


FIG. 10-9

Perspective showing 3-in. or 4-in. free standing furring with 2-in. partition tile or furring at brick pilaster

The method of application of split-furring tile to masonry walls is shown in Fig. 10-8. A typical free-standing furring application is shown in Fig. 10-9.

CHAPTER 11

CONSTRUCTION OF BRICK AND TILE WALLS

1101. GENERAL

The following specifications are suggested as the masonry section covering structural clay products of a general construction specification and, when supplemented by the general conditions, plans, details and schedules, should provide the contractor with sufficient information to estimate costs and to construct the work. These specifications do not include concrete masonry units, glass block, stone or plain (unreinforced) concrete. Where these materials are included in the masonry contract, the specification should be supplemented with suitable provisions. It will be found, however, that many of the requirements relating to brick and tile are equally applicable to other types of masonry construction.

This specification is recommended as part of an architectural specification; and for small jobs, such as one- and two-family residences and small commercial and industrial buildings, it may be simplified, particularly Sections 1102 (a) on Masonry Units and 1102 (c) on Workmanship.

Copies of the ASTM specifications referred to are available from the offices of the American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pennsylvania. Specifications of the Facing Tile Institute may be obtained from the Institute at 1520 18th Street, N. W., Washington 6, D. C.

In the sections which follow, the specifications and construction methods are discussed and recommendations are presented for cold weather construction, cleaning, painting, the application of stucco and plaster, and the repair and maintenance of masonry walls.

1102. SPECIFICATIONS FOR MASONRY CONSTRUCTION

(a) Masonry Units.

1. The sizes of masonry units shall be as indicated on the plans.

2. Facing Brick shall conform to the requirements of ASTM Specifications C216–, Grade MW and Type —— (specify Type FBX, FBS or FBA). The color and texture shall be similar to the panel selected by the architect.

3. Building Brick shall conform to the requirementst of ASTM Specifications C62–, Grade SW for foundations or other structures below grade or in contact with earth, Grade MW for other exterior walls and Grade NW where not subject to the action of weather or soil.

4. Glazed Structural Facing Tile shall conform to the requirements of the specifications of the Facing Tile Institute for ——— (specify Color Ceramic Glaze, Clear Glaze or Salt Glaze, and grade). Color shall be ——— (see Facing Tile Institute color list).

5. Structural Clay Facing Tile shall conform to the requirements of

ASTM Specifications C212–, Type —— (specify Type FTX or FTS) and Class ——— (specify Standard or Special Duty).

6. Structural Clay Load-Bearing Wall Tile shall conform to the requirements of ASTM Specifications C34–, Grade LBX when exposed to weather or soil and Grade LB when not subject to the action of weather or soil.

7. Structural Clay Non-Load-Bearing Tile shall conform to the requirements of ASTM Specifications C56–.

(b) Mortar.

1. Mortar and mortar materials shall conform to the requirements of the ————— (specify Proportion or Property—see Chapter 5) Specifications for Mortar of the Structural Clay Products Institute.

2. Type A mortar shall be used for all reinforced masonry lintels or other structural members, foundations, and masonry in contact with earth.

3. Type A or B mortar shall be used for all other exposed masonry and for load-bearing walls of hollow masonry units.

4. Type A, B or C mortar shall be used for all other masonry.

(c) Workmanship.

1. All masonry shall be laid plumb and true to lines.

2. Brick masonry shall be laid with full mortar joints. Mortar beds shall be spread smooth or only slightly furrowed. The ends of brick shall be buttered with sufficient mortar to fill the end joint. The vertical longitudinal joint in solid brick walls shall be completely filled by parging, by pouring the vertical joint full of grout, or by shoving. Slushing of joints after laying should not be necessary. Closures shall be rocked into place with the head joints thrown against the two adjacent brick in place.

3. Horizontal cell structural clay tile units, exceeding 4 in. in thickness, shall be laid with divided bed joints and, where the units contain a drainage channel to conduct moisture to weep holes, this channel shall be kept free of mortar. Head joints of horizontal cell units shall be placed on both sides of the tile and sufficient mortar shall be used so that excessive mortar will be squeezed out of the joints as the units are placed in position. Head joints may be buttered on both edges of the tile to be placed or one joint may be buttered on the tile in place and one on the opposite edge of the tile to be placed.

4. All vertical cell structural clay tile units shall be laid with divided head joints and, when such units are exposed in exterior walls, care shall be exercised to prevent continuous mortar joints through the wall.

5. All collar joints in exterior tile or brick and tile walls shall be completely filled with mortar. This shall be done by parging either the back of the facing or the face of the backing.

In laying brick and tile masonry, avoid over-plumbing and pounding of the corners and jambs to fit stretcher units after being set in position. Where an adjustment must be made after the mortar has started to set, the mortar shall be removed and replaced with fresh mortar.

6. Non-bearing partitions, in locations where suspended ceilings do not occur, shall extend from the top of the structural floor to the bottom surface of the floor construction above and be wedged with small pieces of tile. The joint at top shall be filled with mortar. In locations where suspended ceilings are used, non-bearing partitions shall extend to ——— (specify in accordance with building code requirements).

7. When the mortar has become thumbprint hard, all exposed joints shall be tooled with a round or other approved jointer. The jointer shall be slightly larger than the width of the mortar joint so that a complete contact is made along the edges of the units, compressing and sealing the surface of the joint. Exterior joints below grade shall be trowel-pointed and all other joints shall be flush cut.

8. Where cutting of glazed or unglazed facing tile is necessary, the cuts shall be made with a motor driven masonry saw.

(d) Bonding.

1. Exposed brick and tile walls shall be laid in center bond or in the bond pattern indicated on the plans. In unexposed masonry all vertical joints shall be broken at least 3 in.

2. All load-bearing masonry walls and partitions shall be bonded each course at corners and intersections and shall be bonded or anchored to connecting work. Non-load-bearing partitions shall be bonded or anchored as indicated on the plans.

3. Brick and composite brick and tile walls shall be bonded through the wall with at least one full header course in each 7 courses or with at least one full length header in each 1½ sq. ft. of wall surface. The distance between adjacent full length headers shall not exceed 20 in. either vertically or horizontally. In solid brick walls of more than 8-in. nominal thickness, the inner joints of header courses shall be covered with another header course which shall break joints with the course below.

4. Multiple-unit tile walls shall be bonded through the wall at vertical intervals not exceeding 34 in. by lapping one unit at least 3½ in. over the unit below or by lapping with units at least 50 per cent greater in thickness than the units below at vertical intervals not exceeding 17 in.

5. Brick and tile veneer shall be tied to the backing by galvanized corrugated metal ties at least ⅞ in. wide and not lighter than No. 22 gauge, or other approved ties. At least one metal tie shall be used for each 2 sq. ft. of veneer and ties shall be spaced not farther apart than 24 in. either vertically or horizontally.

6. Multiple-unit non-bearing partitions may be bonded as specified for walls, paragraphs 3 and 4, or as specified for veneer, paragraph 5.

7. Cavity walls shall be bonded with steel ties 3/16 in. in diameter or metal ties of equivalent stiffness coated with a non-corroding metal or other approved coating. At least one tie shall be used for each 3 sq. ft. of wall surface.

Where hollow masonry units are laid with cells vertical, rectangular ties shall be used. In other walls Z-shaped ties shall be used. Rectangular ties shall be 6 in. long, approximately 2 in. wide, with ends lapped, and Z-shaped ties shall be 6 in. long, with 2-in. ends bent to 90-degree angles.

Ties shall be embedded in a horizontal joint of the facing and backing. Additional bonding ties shall be provided at all openings spaced not more than 3 ft. apart around the perimeter and within 12 in. of the opening.

(e) Anchorage.

1. When intersecting bearing walls are carried up separately, the perpendicular joint shall be regularly toothed or blocked with 8-in. maximum offsets and the joints provided with metal anchors having minimum cross section of ¼ x 1½ in. with ends bent up at least 2 in. Such anchors shall

be at least 2 ft. long and the maximum spacing shall be 4 ft. Masonry walls abutting or adjoining the frame of a skeleton frame building shall be similarly anchored.

2. Non-bearing partitions, when anchored to abutting or intersecting walls or partitions, shall be anchored with metal ties or clips at least ⅞ in. wide and not less than No. 16 gauge galvanized iron at vertical intervals not less than 4 ft.

3. Brick and tile facing against concrete shall be anchored to the concrete by the use of dovetailed anchors inserted in slots built into the concrete. Anchors shall be at least ⅞ in. wide and not less than No. 16 gauge galvanized iron. They shall be spaced not more than 18 in. vertically and 24 in. horizontally.

4. Two-in. split furring and 2-in. open back (split) glazed or unglazed facing tile shall be anchored to the backing with hardware cloth ties consisting of ½-in. mesh, No. 20 gauge galvanized iron fabric, at least 4 in. wide and extending at least 3 in. into the masonry and to within ½ in. of the face of the furring, or by other approved ties. Ties shall be spaced not farther apart than 24 in. vertically and 36 in. horizontally.

(f) Wetting Brick and Tile.

1. All brick having absorption rates (determined in accordance with ASTM Specification C67–) in excess of 0.7 oz. per min. shall be wetted sufficiently so that the rate of absorption when laid does not exceed this amount, except brick to be used with grouted masonry for which the rate of absorption when laid may be 1.4 oz. per min.

2. Structural tile having absorptions (1-hr. boil) of 12 per cent or more shall also be wetted before laying.

3. The units shall be wetted from 3 to 4 hr. before they are used and the method should be such as to insure that each unit is uniformly wetted. All units shall be free from water adhering to their surfaces when they are placed in the wall. During freezing weather units that require wetting shall be sprinkled with warm water just before laying.

(g) Parging and Dampproofing.

1. The outside of basement walls in contact with the earth shall be parged with a ½-in. coat of Type A mortar trowelled smooth, bevelled at top and coved out to the edge of the footing. This parging shall extend to 4 in. above finished grade, to the level of under side of area walls, and at least 12 in. on to area, porch and garage walls.

2. After the parging has set for at least 7 days and when the surface is dry, it shall be covered with a dampproofing consisting of one coat of creosote oil and two coats of coal tar pitch. The pitch shall be heated to flow freely but not above 350° F. Dull or porous spots appearing after application shall be remopped with pitch.

(h) Storage of Materials.

1. All mortar materials shall be stored under cover in a dry place.

2. Brick and structural tile shall be piled on plank platforms in a dry location. During freezing weather all masonry units shall be protected with tarpaulins or other suitable material. Structural facing tile, both glazed and unglazed, shall be covered at all times.

(i) Protection of Work. During erection all walls shall be kept dry by covering at the end of each day or shutdown period with canvas or water-

proof paper. Partially completed walls not being worked on shall be similarly protected at all times. Covering shall overhang at least 2 ft. on each side of the wall.

(j) Freezing Weather.

1. No masonry shall be laid when the temperature of the outside air is below 40° F. unless suitable means are provided to heat the masonry materials and protect the completed work from freezing.

2. Protection shall consist of heating the masonry materials to at least 40° F. and maintaining an air temperature above 40° F. on both sides of the masonry for a period of at least 48 hr. if Type A mortar is used and 72 hr. if Types B or C mortars are used. These periods may be reduced to 24 and 48 hr., respectively, if high-early-strength cement is used.

(k) Pointing and Cleaning.

1. At the completion of the work, all holes or defective mortar joints in exposed masonry shall be pointed and, where necessary, defective joints shall be cut out and repointed.

2. Exposed masonry shall be protected against staining from wall coverings or other sources and excess mortar shall be wiped off the surface as the work progresses.

3. At the completion of the wall, all exposed masonry shall be thoroughly cleaned. If stiff brushes and water do not suffice, the surface shall be thoroughly wetted with clear water and then scrubbed with a solution of not more than one part hydrochloric (muriatic) acid to nine parts water, followed immediately by a thorough rinsing with clear water. If masonry is cleaned with an acid solution, all sash, metal lintels and other corrodible parts shall be thoroughly protected.

Note: Green stain or efflorescence resulting from vanadium salts in the masonry must not be treated with an acid solution. To remove this stain, follow the recommendations of the manufacturer of the masonry units.

4. Acid solutions shall not be used for cleaning glazed facing tile. Upon completion of the work, all surfaces of glazed wall units shall be washed with soap powder and warm water, applied with a fiber scrubbing brush, and then rinsed thoroughly with clear water. Metal cleaning tools and brushes or abrasive powders shall not be used.

(l) Caulking. Outside joints at the perimeter of exterior door and window frames should be not less than ¼ in. nor more than ⅜ in. wide and shall be cleaned out to a uniform depth of at least ¾ in. and filled solid with an approved elastic caulking compound forced into place with a pressure gun. Caulking compound shall be elastic and waterproof and shall gradually form a thin, tough skin on exposed surfaces while remaining plastic indefinitely beneath the surface. It shall not be affected by long exposure to extremes of outside temperature.

(m) Joining of Work. Where fresh masonry joins masonry that is partially set or totally set, the exposed surface of the set masonry shall be cleaned, roughened, and lightly wetted so as to obtain the best possible bond with the new work. All loose brick and mortar shall be removed.

(n) Built-in Work. The masonry contractor shall build in all sash frames, louvres, clean-out doors and so forth, provided and installed by other trades.

(o) **Flue Linings.** Flue linings shall be furnished and installed as indicated on the plans. Flue linings shall start not less than 8 in. below the center line of smoke pipe intakes, or in the case of fireplaces from the apex of smoke chamber, and shall extend continuously 4 in. above chimney masonry. Flue linings shall be set in full beds of mortar with joints smooth on the inside. A cement wash of Type A mortar shall be provided to slope from the edge of chimney masonry to within 2 in. of top of flue lining.

(p) **Flashing.** Furnish and install flashing as indicated on the plans. Unless otherwise indicated, flashing shall extend through the wall and be turned up at the inside face of the wall. Flashing shall project not less than 6 in. beyond jambs and shall be sloped at all points to drain to the outer face of the wall. Three-eighth in. diameter weep holes, spaced 24 in. on centers, shall be provided in the exposed face of the wall above the flashing in the mortar joint in which the flashing is placed.

(q) **Lintels.** Provide and install lintels as shown on the plans. Lintels may be of reinforced brick masonry, reinforced tile masonry or steel angles. In precasting reinforced tile lintels, care should be taken to insure complete filling of cells with mortar and true alignment of the lintel with uniform mortar joints on exposed surfaces. Reinforced brick masonry lintels shall be built in place and the mortar joint or interior space in which the reinforcing rods are placed shall be filled solidly with mortar.

(r) **Parapet Reinforcement.** Furnish and install reinforcement for parapets as indicated on the plans. Vertical reinforcement shall extend into the wall below the roof line not less than 40 diameters or, if dowels are provided in the roof slab, the dowels shall extend into the parapet not less than 40 diameters.

1103. MATERIALS

(a) **Acceptance.** Evidence that all masonry units and mortar materials meet the requirements of the specifications should be obtained well in advance of starting the work. In many instances suppliers can furnish reports of tests indicating compliance of their products with specification requirements. If laboratory tests are required, samples for testing should be obtained well in advance of the shipping dates for the materials. A minimum of 10 days should be allowed the laboratory for completing and reporting tests.

(b) **Receiving and Storing.** In order to expedite the work, it is very important to check the shapes, sizes and quantities as soon as they are received on the job. An itemized list of material should be prepared from the original estimate and deductions made from each item as the deliveries are received. To provide insurance against job delays, any shortages or omissions should be reported at once so that replacements can be made.

On large projects, the estimates should be made so that the requirements for a single building unit may be obtained directly from the summary list. In some cases it is very desirable to have the materials itemized by rooms so that delivery can be made to the most accessible locations.

When stored on the outside, all masonry units should be piled on plank platforms, preferably in a high, dry location. The various sizes and shapes should be placed in separate piles and in the proper order for use

as needed on the job. During freezing weather, all material should be covered with tarpaulins, or building paper. Structural clay tile used for facing purposes should be covered at all times.

1104. WORKMANSHIP

(a) Layout. It is good practice to lay the first course of units experimentally without mortar to determine the width of head joint required, so that the units may be laid without cutting. On short runs and narrow piers, however, some cutting and fitting may be required unless the job is laid out in multiples of unit lengths plus the mortar joint. With the development of modular coordination of building material and general acceptance of dimensional coordination by architects and engineers in the design of buildings, the use of modular masonry units should go far to eliminate expensive adjustments of this nature, so often necessary in the past.

(b) Mortar. After the mortar materials and mix have been determined, provision must be made to maintain the correct batch proportions throughout the entire job. The use of corrected measuring boxes is recommended, although this method is not in general use. At the start of the job it is very important, however, to determine the amount of dry ingredients per cubic foot of material as received. Since bag batches are generally used, the amount of portland cement and dry hydrate are readily controlled. The quantity of dry sand and lime in putty, on the other hand, must be carefully determined.

Sand, as delivered on the job, contains a certain amount of moisture which causes it to swell or "bulk". If volume proportions are used without consideration of this characteristic, the mix will result in a shortage of sand. If the proportioning is done by counting the number of shovels, the pyramiding of moist sand may cause over-sanding. Eighty lb. of dry sand is considered equivalent to a cubic foot for volume proportion. After the weight of dry sand in a given volume of damp sand is determined, a fairly accurate control of the amount of sand may be had by filling a wheelbarrow to a predetermined level. Adjustment must be made, however, as a change of the moisture content of the sand is noted.

(c) Brick. To secure the desired performance of brick masonry, good workmanship is essential and should not be sacrificed for speed of production. A skilled artisan will, however, produce good workmanship at relatively high speed, for his knowledge of the essentials automatically guides his technique.

In the National Bureau of Standards investigation of wall strength (BSRP 108), two classes of workmanship were employed to determine their effect upon wall strength, and similar procedure was followed in other tests for moisture penetration. These two classes were called "Ordinary" (Type B) and "Inspected" (Type A) workmanship, and are described as follows:

"Ordinary" workmanship may be considered as that very closely approximating the quality of work generally obtained in commercial construction where close supervision is not obtained and the first consideration is economy. This class of workmanship is characterized by the furrowing or grooving of mortar beds, very little mortar in the end joints, and almost no mortar in the collar (vertical longitudinal) joints. This type of workmanship showed

lower strengths and less satisfactory results in practically all investigations than better workmanship.

"Inspected" workmanship is that which may be obtained under a definite specification, followed by careful supervision. In this class of workmanship the mortar beds are spread smooth or only slightly furrowed, the ends of the brick are buttered with sufficient mortar to completely fill the end joint when the brick is in place, and the vertical longitudinal joints are completely filled by slushing. The same results may be obtained by pouring the interior vertical joints full of grout, by the "pick and dip" method or by "shoving"; the object being to obtain a solid masonry mass entirely free from voids or open joints.

The above classifications pertain to the assembling of materials into a structural mass of brick masonry. Workmanship also includes other functions of great importance in the stability and appearance of brick structures. Brick should be laid on level beds and to plumb vertical lines. Wythes should be well bonded by headers, or as otherwise required. Architectural patterns and surface bonds should be carefully laid out in advance and carefully executed in the work, and horizontal and vertical joint thicknesses should be determined to work to openings and corners with the minimum of variation.

Bricklayers should, at all times, keep in mind the requirements of the other trades in order to build in or make proper provision for the installation of the other branches of the work. All such built-in work should be solidly bedded in mortar or grout.

(d) Horizontal Cell Tile. Tile units exceeding 4 in. in thickness are generally laid with divided mortar joints. Many units in side-construction tile contain a recess in the center to prevent placing a through mortar joint. Other units are available with a drainage channel to divert any moisture, which may penetrate the outer surface, to weep holes or foundation drains.

Head joints should be carefully placed on both sides of the tile, when laying backing units as well as single unit walls of structural tile. Sufficient mortar should be used so that the excess mortar will ooze out of the joints as the unit is placed in position. The head joints are usually "buttered" on both edges of the tile to be placed, or one head joint may be buttered on the tile in place and one on the opposite edge of the tile to be placed.

All data on the permeability of masonry walls seem to indicate that faulty head joints are the principal contributing factor to leakage. For side-construction units it is very difficult to produce a satisfactory head joint 8 in. high on ¾-in. end shells. Accordingly, for the construction of exposed hollow tile walls subjected to severe exposures (heavy rains, accompanied by high winds), double or cored shell tile or single shell units having overall shell thickness exceeding the minimum shell thickness requirements of ASTM Specifications for Structural Clay Load-Bearing Tile should be recommended for head jonts exceeding 5 in. in height.

All joints on the exterior face of the wall should be tooled to give a concave surface. This compresses the mortar and helps seal any small cracks between the unit and mortar joint. It will not, however, correct the

broken bond due to tapping a unit into line after it has been laid. When adjustments of this type are necessary, the old mortar should be removed and replaced with fresh mortar.

(e) Vertical Cell Tile. Most partition tile and many types of backing and single and multiple unit wall tile are designed for use in the wall with the axes of the cells in the vertical position. In general, standard single shell units are used for all types of interior walls and backings, while double, cored shell and heavy single shell units are preferred for exterior walls exposed to the weather. Many successful exposed installations have been made, however, with standard units, particularly for low-cost housing, garages and storage buildings. It has been found that the narrow bed joints are thoroughly compacted, due to the weight of the units above. When properly tooled, as recommended above for side-construction units, the bed joints can be made highly impervious.

No mortar should be placed laterally through the wall on the connecting webs and end shells, except, of course, at wall ends and corners, unless the units are especially designed for complete shell and web alignment.

Head joints of interior non-load-bearing partitions of all sizes may be buttered on both sides, but care must be taken so that the mortar remains in place while the unit is shoved into position. For load-bearing walls, 6 in. or more in thickness, the end joints should be carefully placed to prevent continuous mortar joints when used in exterior exposed walls. Some end-construction units are available with recessed ends which insure an open space or divided joints. Sufficient mortar should be used in all cases to cause the mortar to ooze out of the joints on both sides of the unit.

(f) Collar Joints. Tests conducted at the National Bureau of Standards and reported in Building Materials and Structures Report, BMS82, "Water Permeability of Walls Built of Masonry Units", by Cyrus C. Fishburn, dated April 1942, indicate that a high resistance to moisture penetration can be obtained when the interior vertical joints between units (collar joints) in composite walls are filled with mortar. This may be done with a parge coat from ⅜ to ½ in. thick, either on the back of the facing or on the face of the backing. In addition, the exterior facing should be carefully placed with full bed and head joints. Special attention should be given to insure full head joints between header units. Mortar for the bed joints should be spread thick and the furrow in the mortar should be shallow so that the excess mortar will fill the furrow when the units are bedded.

(g) Covering. Proper covering of the wall in time of inclement weather is essential for good construction. Many fine buildings have been damaged by lack of precautions at such times. Covering of unfinished walls by tarpaulins or heavy waterproofed paper, securely tied or weighted in position, should be specified and rigorously enforced. Mortar boards and scaffold boards should not be accepted as suitable covering.

1105. WETTING BRICK AND TILE

Laboratory tests as well as the performance of brick and tile walls in service indicate that a strong and complete bond cannot be obtained between

mortar and high absorption brick and tile units laid dry. Good mortar bond is essential to both strength of masonry and resistance to rain penetration and such a bond can be obtained with units of high absorption if they are properly wetted before laying.

A rough but effective test for determining what units give improved bond by wetting consists in drawing a circle 1 in. in diameter, on the surface of the unit which will be in contact with the mortar, with a wax pencil, using a 25-cent piece as a guide. With a medicine dropper, place 20 drops of water inside this circle and note the time required for the water to be absorbed. If the time exceeds 1½ min. the unit need not be wetted; if less than 1½ min. wetting is recommended.

A satisfactory procedure for wetting brick and tile consists of playing a stream of water on the pile until water runs from each individual unit. This should be done several hours before the units will be used so that the surfaces will have an opportunity to dry before they are laid. Wetting of low absorption units or the excessive wetting of other units which results in water on the faces when they are laid is undesirable and will cause "floating" and bleeding of the mortar.

1106. BONDING

Both the strength and appearance of brick and tile walls are affected by the bonding of units. Longitudinal bonds and patterns should be laid out in advance of the work and checked carefully as the work progresses. Relatively slight variations in patterns may destroy the desired effect.

Through - the - wall or structural bonding units (headers or bonding stretchers) should be bedded in full mortar joints and particular care should be exercised to obtain full head joints since wall leakage frequently occurs at header courses.

Corners of brick and tile walls should be bonded every course and no unit less than 4 in., horizontal face dimension, should be used at a corner or jamb.

Fig. 11-1 and 11-2 show methods of bonding brick and tile walls, respectively.

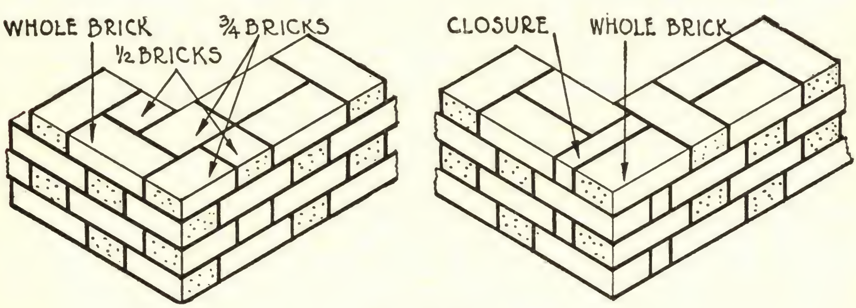


FIG. 11-1

Dutch corner bond *English corner bond*

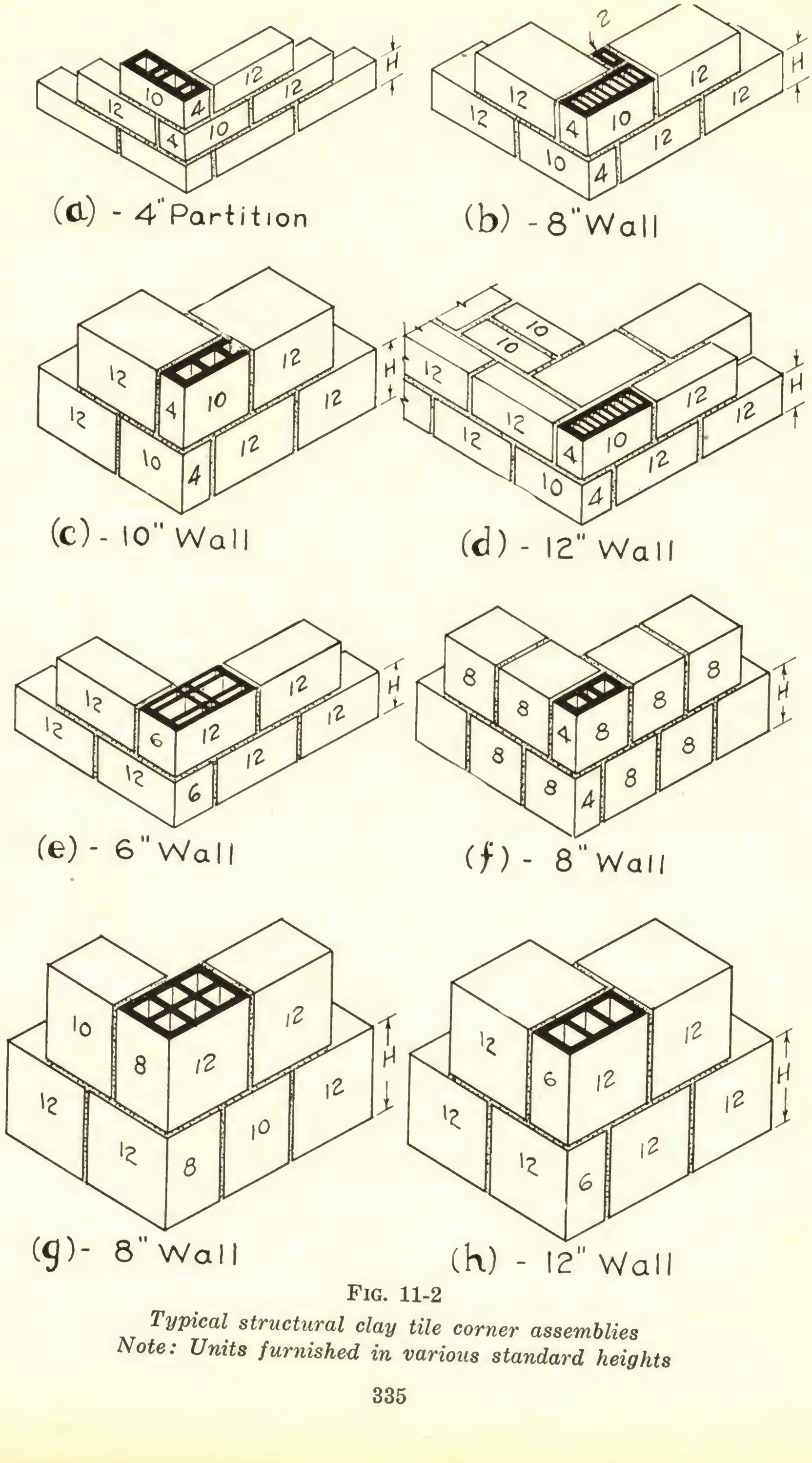


FIG. 11-2

Typical structural clay tile corner assemblies
Note: Units furnished in various standard heights

1107. MISCELLANEOUS CONSTRUCTION METHODS

(a) Bearing Courses. Wherever wood or masonry floor systems are supported on walls of vertical cell tile construction, a bearing slab of tile not less than 1 in. in thickness should be provided for bearing purposes. For joist bearing on foundation walls some building code regulations require at least 4 in. of solid masonry. This is a detail of particular importance in termite infected areas and in construction where wood frame supporting members are used. In most localities, joists and floors are placed directly on conventional horizontal cell units or on tile slabs where end-construction units are used as described above. The space between all floor joists should be completely filled with masonry.

(b) Nailing Plugs, Blocks and Anchors. Wood nailing blocks used for fastening furring, grounds, picture molds or other surface fixtures should be of seasoned soft wood creosoted to prevent shrinkage and rot. They should be placed in the vertical joints only and never in the horizontal bed.

Metal nailing plugs are recommended as providing better construction. They may be built into the joint when the tile is erected but it requires additional care to locate them exactly where required. This is not a serious problem when used for base boards, chair rails, or picture molds, however, it may be difficult to determine the location for plumbing fixtures, cabinets and shelving. With layouts incorporating modular coordination on the 4-in. increment, the exact location for inserts of this type can be readily obtained—in addition, fixture sizes will be standardized on the 4-in. increment so that spacing will be uniform for the various makes. There are numerous types of metal devices for attaching fixtures to tile walls and partitions without requiring special backing or reinforcing. Various methods are illustrated in Fig. 11-3. As required, holes may be placed directly through the face shells of the tile with hard steel or carbide tipped drills. In some cases where softer tile are used as in plastered partitions, small holes may be made by the use of an ordinary ⅛-in. punch and hammer. Corner beads or metal furring may often be attached in this manner by fastening with U-shaped staples.

Brick size porous clay nailing blocks are also available in some localities; since the material is completely inert, there is no danger of nail disintegration from chemical reaction.

(c) Furring Applications. Although there are many examples of structural clay tile and composite brick and tile walls with plaster finish applied directly to the interior surface, furring on 8-in. masonry walls is recommended in northern areas particularly for residential construction. Furring may be of wood, hollow tile or metal, depending upon the type of construction and the local building requirements.

Wood furring generally consists of 1 x 2-in. or 2 x 2-in. strips, applied vertically to the face of the wall by nailing into blocks, wood or metal plug inserts or directly into the mortar joint by the use of case hardened "cut" nails or special spiral-threaded masonry nails.

Furring strips may also be fastened with expanding or "self-clinching" nails, driven into the end joints, or collapsible steel screw sockets may be used. Special anchor nails fastened to the masonry wall with adhesive cement is a recent development for installing furring and plaster grounds. They are easily and quickly installed without drilling, plugging or nailing.

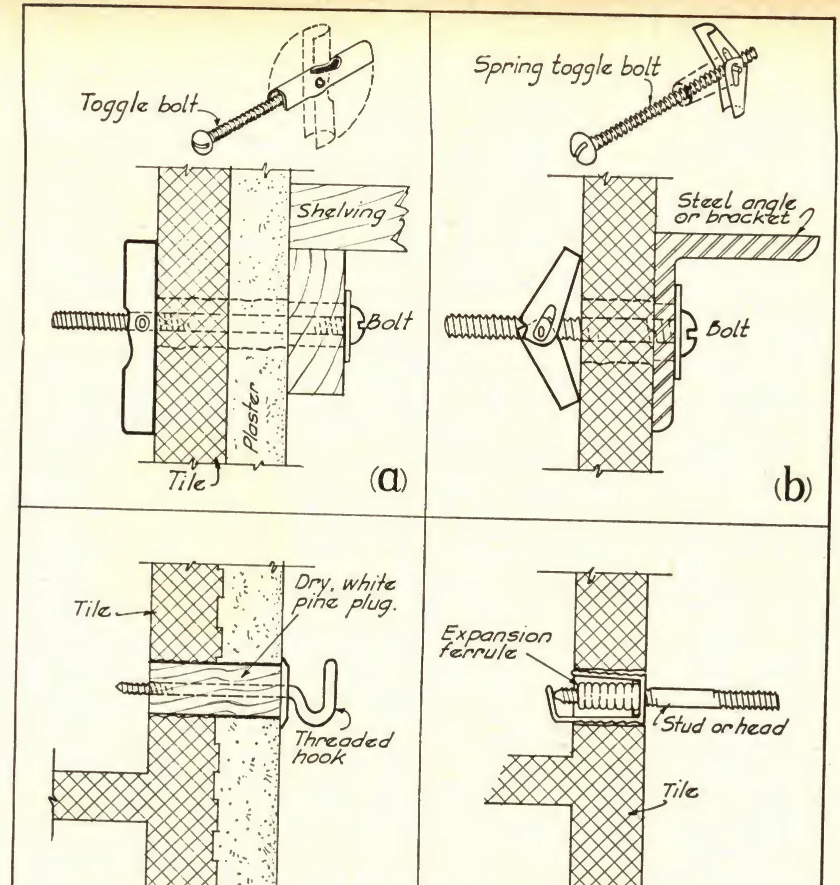


FIG. 11-3
Typical methods of attaching trim, shelving, fixtures, etc., to structural clay tile walls and partitions

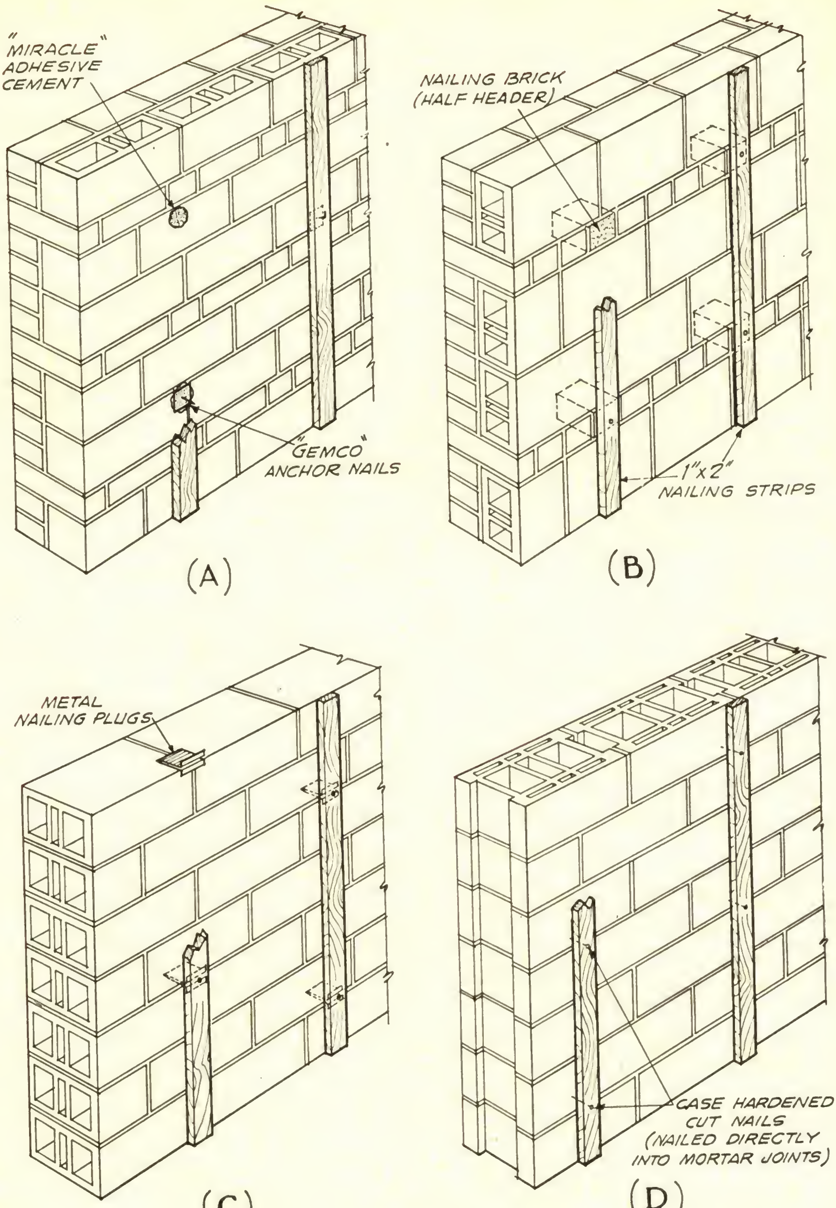


FIG. 11-4

Wall details showing various furring methods

Spacing of furring strips is determined by the width and thickness of the lath, plaster or insulation board, but is usually 16 in. on center. Several methods of attaching wood furring strips are illustrated in Fig. 11-4.

Metal furring strips consist of standard light steel channels fastened by either tie wires built into the mortar joints or by special clips designed for this purpose.

Tile furring may be free standing or anchored to the walls with metal ties, or 10d nails driven into the joints and bent over the top edge. Split furring tile 2 in. in thickness and 12 in. square are generally used. For this size the ties are spaced every two courses in height and not farther apart than 3 ft. horizontally. The use of furring tile is described and illustrated in Chapter 10.

(d) Framing at openings. Door and window openings which are to receive trim must be provided with means of fastening to the masonry. This usually consists of a framing around the opening commonly called a "rough-buck" and may be of wood or metal construction. Door bucks are set in the exact position as shown on the plans and anchored to the floor and temporarily braced in a true position. As the masonry is built up solidly against the buck, metal anchors are attached to the buck and bedded into the mortar beds. With vertical-cell tile, 10d nails may be driven into the bucks and clinched over the end shell.

Combination door bucks and jambs of pressed metal are often used with masonry partitions. Corrugated adjustable anchors are furnished for approximately each 2 ft. of opening height. For heavy-duty openings, steel channel frames are generally used.

(e) Lintels. Openings in masonry walls must be provided with arches, a lintel of reinforced masonry, steel angles or tee sections. Lintels should have a full bearing of at least 4 in. nominal at each end.

Reinforced tile lintels may be precast or constructed in place; the former being general practice for openings up to 5 ft. in width. Precast lintels are made at the job-site, in a suitable location, by placing the tile end to end against an inclined plank form or template, with proper precaution to secure uniform mortar joints for exposed work. Steel reinforcing is placed through the cells and secured in the proper position with bar-centers approximately ¾ in. from the inside shell surface. Bars should protrude about ½ in. from the ends so as to indicate the location of the bottom or soffit of the tile. With inexperienced labor or if extra handling is required, additional reinforcing of the required size is sometimes used at the top of the unit. After the cells are packed with concrete or rich cement mortar, they should be moist-cured for at least 7 days before placing.

Reinforced tile lintels constructed in place are made by laying a course of tile over the opening on a temporary wood centering. As the units are placed in position the cells are filled solidly with cement mortar. When the required width is reached, reinforcing bars are placed through the filled cells. After securing in the proper position, the mortar should be thoroughly tamped around the bars and additional mortar packed into the end before the next wall unit is placed into position.

Special U-shaped tile units are also available in some localities. The open top permits placing the bars in a mortar bed and filling with concrete or mortar directly from above. If desired, these units may also be used for precast lintels.

Reinforced brick masonry lintels may be precast by following the same general procedure as outlined for precast tile lintels; however, they are usually built in place. For relatively short spans (3 to 5 ft.) one or

two ¼-in. reinforcing bars per 4-in. width of lintel is adequate reinforcement. The required ¼-in. bars should be embedded in the first mortar joint above the soffit of the lintel which is supported on shoring and the wall constructed above in the usual manner.

Reinforcing bars should extend a minimum of 6 in. beyond the jambs of the opening and all mortar joints in the lintel, particularly the joint containing the reinforcement, should be filled solidly with mortar.

For longer spans or where the lintel supports floor joists or other loads, and heavier reinforcement is required, the lintel may be constructed as in Fig. 7–13, Chapter 7. Either design is satisfactory from a structural standpoint, the choice depending upon the reinforcement required. In either case the space enclosing the reinforcing rods should be filled solidly with mortar.

No additional precautions need be taken to support the soffit brick below the reinforcement, since the bond stress developed, due to the weight of one brick (5 lbs. or less) is less than 1 psi, and the strength of bond between Type A mortar and brick will vary from 60 to 100 psi, depending upon the surface of the brick and the workmanship employed.

(f) Cutting. During the past several years rapid advancements have been made in tools with which to cut structural clay products. Specially designed masonry saws are now used to provide precision angles, outlets and shorter lengths on the job or in the plant.

Regular wood cutting saws should not be used for masonry work for several reasons. The motors must be totally enclosed to withstand abrasion, moreover a different cutting principle is necessary for masonry materials. Masonry saws utilize a ⅛-in. thick silicon-carbide blade, bonded with resonoid. For full efficiency the blade must not be jammed into the tile, but instead the material being cut should be moved back and forth beneath the blade completing a rapid series of cuts. This principle of operation lessens the arc of contact on the blade, which is absolutely necessary to assure the complete elimination of cut away particles, thereby greatly increasing blade life.

Actually, by tests it is found that a masonry saw equipped with a 1½ H.P. motor will complete a cut through a 4-in. glazed brick in 22 to 32 sec., while the jam or wood cutting principle will greatly reduce the cutting speed as well as decrease blade life.

It is generally best to cut completely through a tile, rather than to score and break, taking into consideration the time required to pick up a hammer and chisel and final trimming necessary. Then too, considerable material can be salvaged when a portion of the tile is sliced away neatly and accurately.

Masonry saws are designed to afford maximum flexibility in handling furring tile as well as the largest clay unit. Foot pedal operation is recommended to give the operator full use of both hands in order to mark the tile and perform the cutting.

1108. COLD WEATHER MASONRY CONSTRUCTION

(a) Discussion. In many localities within comparatively recent years, it was considered good practice to discontinue all masonry construction during the severe winter months. Most projects were planned so that this

portion of the work could be done in the summer and early fall, thus creating an unusual demand for workers during these months which was followed by a long period of unemployment. To a certain extent, this was justified when slow setting lime mortars were used. The use of these mortars necessitated long protective periods for the masonry walls and since the protective methods and equipment in use at that time were costly, only a few of the larger contractors were properly equipped to carry on winter masonry construction.

During recent years, however, mortars containing portland cement in varying amounts have come into almost universal use and the shorter setting time of these mortars has subtantially reduced the protective periods required for masonry walls built in sub-freezing temperatures. Protective methods and equipment have been improved until brick and tile masonry may now be constructed economically throughout the year in nearly every section of the United States.

While the cost of protective measures required to prevent masonry from freezing before it has acquired sufficient strength to resist the loads to which it may be subjected, and to insure its durability, is an additional item of expense over the cost of summer construction, there are other compensating items which will frequently make the cost of winter construction no greater, and sometimes less than the cost of similar work constructed during the summer months. The most important of these compensating items is the greater availability of labor and materials during the "off-season." Several contractors report that the production of their masons during the winter months exceeds the average production during the summer and the yearly labor costs of the contractors who operate on a yearly basis is substantially less than if work is carried on only during the warmer months. Building materials can usually be obtained at somewhat reduced prices during the winter because of the smaller demand and the desire on the part of supply dealers and manufacturers to keep their men employed. Shipping facilities are less crowded during the winter months and deliveries can, as a rule, be made more promptly.

(b) General Requirements. Since jobs vary as to size, layout, height, general design, material protection, location in respect to adjoining structures and in many other respects, the most economical methods of protecting and heating the particular project should be studied before detailed procedures are established. In general, the items to be considered in the protection of masonry construction in sub-freezing weather are the following:

1. Proper storing of materials. All masonry units and mortar materials should be placed on plank platforms and thoroughly covered with tarpaulins or building paper. Planks should be raised to prevent absorption of moisture from the ground. Masonry units and mortar materials should never be permitted to become coated with ice or snow. Carelessness in the storing of materials promotes poor workmanship and increases the cost of laying, as the removal of ice and snow, and the thawing of masonry units are absolutely necessary before construction is started. Since the cost of acceptable covers is no real burden to the job, specifications for cold weather masonry should include the use of such platforms and covers, and forbid the use of unprotected materials exposed to the weather.

2. Preparation of Mortar. Batch concrete mixers for mixing all types of mortar are recommended on all larger jobs and they are sometimes eco-

nomical on smaller jobs. Modern mixers are equipped with a skip hoist, water tank and water measuring device which control the mix and produce well-mixed mortar of the right workability. Steel mortar boxes may be used on smaller jobs. The boxes should be raised about one foot above the ground on piers built of brick laid dry. Waste building wood or steam may be used to keep the mortar warm after mixing.

The mixing water and sand should be heated not to exceed 160 degrees F. The mortar sand should be heated uniformly. Scorched sand (with a reddish cast) should never be used in the mortar. Scorching can be prevented by heating slowly and evenly. This can be done by piling the sand around an old metal smoke stack section laid horizontally, in which a slow fire is built, or through which steam pipes may be run. In freezing weather, both the water and sand should be heated.

Temperature of the mortar when used should not exceed 120 degrees F. or be lower than 70 degrees F. The use of salt to lower the freezing point of the mortar should not be permitted.

3. Heating the Materials. Heating of masonry units is also recommended in severe weather. To prevent sudden cooling of the warm mortar in contact with cold units, it is recommended that all hollow masonry units be heated when the outside temperature is below 18 degrees F. and that all solid units be heated when the outside temperature is below zero. In hollow masonry construction, the ratio of net unit weight to mortar weight per cubic foot is approximately 4.6. With solid masonry units the ratio is approximately 2.6. Actually, the same amount of mortar will lay almost twice the actual solids content in hollow units. Masonry unit heating methods should be given careful study and, where required, storage should be provided so that heating may be facilitated at minimum expense.

Brick, having rates of absorption above 0.7 oz. per min. should be wet with warm water just before laying; those with lower rates of absorption can be laid dry.

4. Laying Precaution. Masonry should never be placed on a snow or ice-covered base or bed because of the danger of movement when the base thaws and the total lack of bond between the mortar bed and the supporting surface. If the walls are properly covered at the end of the work period or in preparation for a "shut-down" period, there should be no necessity for ice or snow removal from walls. In the event, however, that the covering is displaced, the bed may be cleaned with live steam. The steam should be applied long enough to thoroughly dry out these parts and, if frozen or damaged, defective parts should be replaced before starting new brickwork.

5. Protection of Walls. Protection of the masonry is required and will vary with the weather conditions. With warm mortar, tarpaulins covering the masonry may be sufficient when temperatures are above 25 degrees F. on a rising thermometer. In severe weather, however, enclosures with artificial heat by steam or coke-burning salamanders are recommended. Walls should not be baked on one side with no protection on the other, but the enclosures should be so arranged as to allow a circulation of warm air on both sides of the wall. Each job is an individual problem. Job layout, desired rate of construction and the prevailing weather conditions all influence the amount of protection and the amount of heat necessary to prevent the masonry from freezing.

When a building is enclosed and only partitions and inside walls are being constructed, the matter of protection reduces itself to the closing of all door and window openings, (before glazing), with heavy muslin.

A further precaution would be the closing of all stair wells and elevator shafts. After taking these precautions, a few well placed "salamanders" should produce the required temporary heat.

1109. CLEANING CLAY PRODUCTS MASONRY

(a) **New Construction.** In the construction of masonry walls the skilled mason will generally keep the surface remarkably free from mortar particles and stains, being trained to take pride in the appearance of his work. There are few other occupations where the individual's character is so readily reflected. At the end of each day, the mason's performance is exposed not only to the critical eyes of the fellow workmen and foremen, but also to the builder and owner. In addition, the completed portion of the wall becomes an important part of the finished structure always exposed to the public view.

One of the important techniques acquired by the mason is the "feel" of or adeptness with the trowel. The proper amount of mortar is taken up each time, until this becomes an automatic operation. It is then carefully placed to prevent the excess mortar from spreading or dropping on the face of the wall as pressure is exerted on the unit. Greater care must be taken when laying rough textured units; also when using the rich cement mortars since they are characteristically less plastic and may have lower water retentivity. With hard unglazed units, bleeding may cause some staining, and particles splashed on smooth unglazed surfaces will leave temporary marks. For this reason most specifications require a final washing down of all masonry work. Typical methods and requirements are as follows:

1. Unglazed Masonry Surface. On completion of the work all masonry must be carefully cleaned down, removing all large particles of mortar with a putty knife or chisel. If acid is required for the removal of mortar stains (see note below), it shall be muriatic (hydrochloric) and not stronger than one volume of the commercial acid to nine volumes of water. Before the acid solution is applied, the surface should be thoroughly soaked with clear water, otherwise the mortar stain may be drawn into the pores causing a permanent dulling of the rich natural masonry colors. The acid solution should be applied with a long-handled, stiff fiber brush, with proper precautions as to covering of clothing, hands, and arms to prevent burns. It should not be placed over an area greater than 15 to 20 sq. ft. before the wall is again thoroughly washed down, or preferably hosed, with clear water immediately after cleaning. It is important to remove all trace of the acid before it attacks the mortar joint. All frames, trim, sills, or other installations adjacent to the masonry must be carefully protected against contact with the acid solution.

(NOTE: Whenever possible, smooth, light-colored units should be scrubbed with warm water and soap powder in lieu of acid cleaning.)

2. Glazed Surface. Acid cleaning is not required for glazed tile masonry. As the work progresses, any excess mortar should be removed with a cloth. Upon completion of the work, all surfaces of glazed wall units may be cleaned down using soap powder and warm water, applied

with a fiber scrubbing brush, and then rinsed thoroughly with clean water. Hard lumps of mortar may be removed by using sharpened wood paddles. Metal cleaning tools and brushes or abrasive powders should not be used.

(b) Old Construction. Processes used in cleaning depend primarily upon the materials to be cleaned and the nature and chemical composition of the spots or stains to be removed. Cleaning clay products is no exception to this general rule. A method which can be used successfully with glazed ware, for instance, may prove entirely unsatisfactory if applied to a rough textured masonry wall. The problem is further complicated by the fact that masonry structures consist of two materials, the clay units and the mortar, each of which has different characteristics—many cleaning compounds to which clay products are entirely impervious have a damaging effect upon mortar.

Texture and absorption* of the clay unit and the nature of the material or stain to be removed also determine to a very great extent the results which may be obtained with various cleaning methods. Proper cleaning methods will restore glazed ware to its original appearance. The same is true of smooth textured brick or tile of relative low absorption, the lower the absorption the better the results which may be expected.

High absorption or rough textured units are more difficult to clean. If the staining material has penetrated into the pores of the clay, it frequently cannot be removed without removing a part of the unit itself, thus destroying the original texture and resulting in an appearance different from the original.

Principal methods of cleaning masonry structures are: sand blasting, steam or steam and water jet and the application of various cleaning compounds. The first two of these methods are used principally on large buildings as considerable equipment is necessary for either method. Cleaning compounds may be applied to either large or small structures.

1. Sand Blasting. Sand blasting consists in blowing hard sand through a nozzle by compressed air against the surface to be cleaned. The sand removes a thin layer from the wall surface, the thickness of the layer depending upon the depth to which dirt or stain may have penetrated the wall. This method is an effective cleaning process; however, it destroys the original texture of the unit and leaves the wall with a coarse texture which is particularly susceptible to the accumulation of soot and dirt. Due to the difference in hardness between clay units and the mortar joints, sand blasting may do serious damage to the joints.

If sand blasting is used, it will frequently be necessary to repoint the mortar joints after the surface has been cleaned; and the application of a colorless waterproofing compound to the roughened surface will tend to make the wall self-cleansing, and will prevent the rapid soiling of the surface from smoke and dust particles in the air. Sand blasting should never be used on glazed ware or other units having special surfaces or textures.

2. Steam or Steam and Water Jets. This method of cleaning consists of washing the wall with a steam or steam and water jet under pressure. It is effective in removing soot and dirt which accumulates on a wall over a period of time. Best results are obtained when it is used on glazed ware

* Porosity, absorption, capillarity and rate of absorption are all factors which affect the cleaning of clay products. In this discussion the term absorption should be understood to include all the above.

or low absorption units; however, it has also been used with fair success on high absorption or rough textured units. It is not effective in removing stains which have penetrated into the pores nor in removing such substances as mortar or paint.

Frequently an alkaline such as sodium carbonate, sodium bicarbonate or trisodium phosphate is added to the cleaning water when the cleaning is done by the jet method. Chemically these compounds are known as salts and, while they aid materially in the cleaning action, some of the salt will be retained in the clay unit (the amount depending largely upon the absorption of the unit) and will appear later on the face of the wall in the form of efflorescence. The amount of the salt retained by the clay units can be materially reduced by thoroughly wetting the surface with clear water before the cleaning solution is applied. The wall should also be washed with an abundance of clear water after cleaning to remove the salt from the surface.

3. Application of Cleaning Compound. This method is applicable to structures of all sizes and is probably used to a greater extent than any of the other methods. On large projects the cleaning contractor develops a cleaning compound best adapted to the particular job. This is done through an examination and analysis of the material and stains to be removed and the strength and chemical composition of the solution is usually adjusted by trial.

4. Treatment of Surface Prior to Cleaning. Most cleaning solutions contain compounds which if absorbed by the clay units will subsequently appear on the face of the wall in the form of efflorescence. For this reason the surface to be cleaned should be thoroughly wetted with clear water before the cleaning solution is applied. A booklet,—"Maintenance of Interior Marble" by D. W. Kessler—which is based upon the results of over 10,000 laboratory tests and experiments, contains the following statement: "The importance of thorough rinsing is so evident and has been so frequently stressed that it hardly seems worth while to emphasize the point here. However, the research upon which many of the recommendations herein are based has indicated that the final rinsing is no more important than the preliminary dampening of the surface with clear water. Where this practice is followed the final rinsing can be more easily and satisfactorily done."

5. Removing Efflorescence. Water applied with stiff scrubbing brushes will frequently remove efflorescence. If this does not do a complete job, apply water first, then scrub with water containing not more than 10 per cent of muriatic (commercial hydrochloric) acid and, immediately thereafter, rinse thoroughly with clean water. It is sometimes desirable to give the surface a final washing with water containing approximately 5 per cent of household ammonia.

6. Treatment for Removal of Stains.

Mortar Stains: The method described above for washing down unglazed masonry wall surfaces after construction is also used for the removal of mortar particles and stains on existing work.

Paint Stains: For fresh paint apply a commercial paint remover, or a solution of trisodium phosphate in water—2 lb. of trisodium phosphate to

one gal. of water. Allow to stand and remove paint with scraper and wire brush. Wash with clear water.

For very old dried paint, organic solvents similar to the above may not be effective, in which case the paint must be removed by sand blasting or scrubbing with steel wool.

The following recommendations are taken from "Maintenance of Interior Marble" by D. W. Kessler, or "Removing Stains from Cast Stone and Concrete"—Concrete Building and Concrete Products Vol. 12, No. 3, March 1937 by R. E. Baumgarten. It is believed that they may also prove effective with clay masonry.

Iron Stains: Mix seven parts lime-free glycerine with a solution of one part sodium citrate in six parts lukewarm water, and mix with whiting or kieselguhr to make a thick paste. Apply paste to stain with trowel, and scrape off when dried out. Repeat until stain has disappeared and wash thoroughly with clean water.—R. E. Baumgarten.

Tobacco Stains: Dissolve 2 lb. trisodium phosphate in 5 qt. of water. In separate vessel make a smooth stiff paste of 12 oz. of chloride of lime in water. Pour the former onto the paste and stir thoroughly. When the lime has settled, draw off the clear liquid and dilute with equal parts of water. Make a stiff paste of this with powdered talc and apply in the same way as described for iron stains.—R. E. Baumgarten.

Smoke Stains: Make smooth stiff paste of trichlorethylene and powdered talc and apply as described above. Cover with glass or pan to prevent rapid evaporation. If slight stain is left after several applications, wash thoroughly and then use the method described under tobacco stains. Precaution should be taken to ventilate a closed space in which trichlorethylene is used, as the fumes are harmful.—R. E. Baumgarten.

Copper or Bronze Stains: Mix together in the dry form, one part of ammonium chloride (sal ammoniac) and four parts of powdered talc. Add ammonia water and stir until a thick paste is obtained. Place this over the stain and leave until dry. When working on polished marble use a wooden paddle to scrape off the paste. An old stain of this kind may require several applications. Sometimes aluminum chloride is used in the above procedure instead of the sal ammoniac.—D. W. Kessler.

Oil Stains: Make a paste of a solution of 1 lb. of trisodium phosphate to 1 gal. of water and whiting which may be obtained at any paint store. Spread this paste in a layer about ½ in. thick over the surface to be cleaned and leave until it dries (approximately 24 hr.). Remove the paste and wash surface with clear water.—D. W. Kessler.

Coal Smoke Stains: Scrub with powdered pumice and wire brush. This is an alternate method to the one given above recommended by Mr. Baumgarten.

7. *Glazed Ware.* In cleaning glazed ware, care should be exercised to select a cleaning compound which will not erode or etch the glaze. Most cleaning preparations contain scouring grit, powdered soap and carbonate of soda. The per cent of scouring grit varies in different cleaners from 30 to 90 per cent and, as it is frequently harder than the glazed unit, it has a tendency to scratch the glaze. Before using a cleaning preparation it should be tried out on a small area to make sure that the scouring grit will not mar the finish. In using cleaning compounds which contain soap powder, soft water should be used or, if it is not obtainable, hard water

should be softened. Trisodium phosphate which may be purchased from laundry supply houses in the form of a white powder may be used as a water softener.

Sodium hydrosulphite, acidified sodium fluosilicate, and ammonium bifluoride have been used effectively with glazed ware and if sufficiently diluted are not apt to etch the glaze. The cleaning solution should be prepared by adding ½ to ¾ lb. of any one of the above to 1 gal. of water. When using these compounds all metal and glass should be protected from the cleaning solution. The cleaner should be mixed in wooden containers and in applying it rubber gloves should be used to protect the hands.

1110. SCAFFOLDING AND TOWERS

(a) General. Scaffolding may be separated into two structural elements; (1) supporting members and (2) platforms. The former may consist either of typical wood construction or of built-up sectional steel tubing, while the platform or "staging" is generally nominal 2 x 10-in. planking for all types.

During the past decade, tubular steel sections have been extensively used for exterior and interior scaffolding on all classes of buildings. They are especially practicable for the modern type of fire resistive buildings, where the fire hazard from flammable scaffolding may be very serious. In some localities, all lumber used for scaffolding must be processed with chemicals to render it fire resistive.

For high steel frame buildings, suspended scaffolds are used when the masonry is laid from the outside. They are supported from above by steel wire cables suspended from outriggers anchored to structural steel members.

Swing or suspended scaffolds are particularly suitable for winter construction since they are relatively easy to enclose with canvas. Protection is thus afforded to the exterior of the building during the most critical period. Salamanders are placed on the scaffolds and working conditions are very favorable and wall temperatures above freezing are easily maintained day and night. Pole scaffolds on the outside are also easily enclosed. However, for "overhand" work from the inside of the building, the canvas enclosure must be supported by outriggers or supplementary pole scaffolds, and the cost of protection is somewhat greater.

The various types of scaffolds generally used by masons include the following:

1. Horse scaffolds
2. Single pole scaffolds
3. Built-up scaffolds
4. Suspended scaffolds
5. Masons' swinging scaffolds
6. Square scaffolds
7. Tubular pole scaffolds.

(b) Horse scaffolds consist of trestles or horses generally 4 to 5 ft. high and approximately 4 ft. long. The horizontal member or "bearer" is 3 x 4 in. and the legs nominal 2 x 4-in. or 1¼ x 5-in. unfinished stock, all properly braced together with 1-in. planks of the required width. Plank platform or

staging supported by the horses are not less than 2 in. nominal thickness and laid with their edges close together.

Horse scaffolds should not be erected more than 3 tiers of horses or more than 12 ft. high. For overhand work from the inside of the building, a single tier of horses is suitable for story heights up to 9 ft. Special "pony" horses approximately 2½ ft. high are sometimes used on the typical single-tier scaffold for story heights up to 12 ft. If only a slight increase in the height of a platform is required, small piers of tile may be built up on top of the scaffold plank to support the raised platform, but not more than 12 in. high. By omitting one or two planks from the platform of the upper or "pony" trestles, a runway is provided for material on the lower tier. Where 2- or 3-tier scaffolds of standard horses are used, supplementary runways are also required in one or two full-tier steps.

(c) **Single-pole scaffolds** consist of a single row of posts or uprights set not to exceed 5 ft. from the building and spaced not more than 7 ft. apart. Minimum post sizes are as follows:

Height	Size
Up to 24 ft.	3 x 4-in.
24 to 40 ft.	4 x 4-in.
Over 40 ft.	4 x 6-in. or heavier as required to support all loads with a safety factor of at least 4.

All posts should be thoroughly braced diagonally and connected horizontally with stringer and ledger members. Putlogs, nominal size 4 x 4-in., to carry the plank platform are supported on a ledger at the outer end, and in a wall recess on the inside. At the completion of the wall the recesses are filled in as the scaffolding is removed. Patching of recesses may be eliminated by the use of metal chocks secured to the wall end of the putlogs. They are inserted into the end joints and are supported on the outer 4 in. of masonry.

(d) **Built-up or independent pole scaffolds** consist of a double row of posts or uprights; the inner row set as near the wall as practicable. Minimum post sizes, allowable heights, and longitudinal spacing are similar to the requirements for single post scaffolds. The platform planking is placed on 2 x 8-in. bearers which in turn are supported on 2 x 8-in. stringers. Diagonal bracing is placed in both directions on the outer row of posts and sometimes on the inner row for very high or heavy duty scaffold.

(e) **Suspended scaffolds** are generally recommended for all buildings more than 5 stories high constructed of structural steel or reinforced concrete skeleton framing. These scaffolds are supported from above by steel wire cables suspended from overhead steel I-beam outriggers. The complete scaffold consists of supporting frame, steel or wood bearers, plank platform, wood railing, toe-board, wire-mesh protection, and plank overhead covering in addition to the hoisting equipment.

Suspended scaffolds are considered the safest and most economical type for laying masonry from the outside of the building. The hoisting machines permit the masons to work waist-high constantly—the least tiring and most efficient level.

(f) **Masons' swinging scaffolds** consist of a platform at least 30 in. wide, suspended with steel wire cables from overhead steel beam outriggers. They are often used for painting or cleaning down new or existing walls. The

platform may be raised or lowered by means of windlass to suit the required working position. Wrought iron hangers or stirrups which support the platform at each end should be so designed as to receive the guard-rail and toeboards. The space between the guard-rail and platform is generally filled with a wire netting screen.

(g) **Square scaffolds** consist of framed wood squares or jacks used in supporting a plank platform in a manner similar to horses or trestle scaffolds. The squares are generally framed from 2 x 4-in. material and are not larger than 5 ft. on each side. Corner bracing is provided on both sides and also 1 x 8-in. diagonal bracing from the center of each frame member to the center of the adjacent member. When the squares are placed in position they are braced laterally by 1 x 6-in. diagonal bracing on both the front and rear sides of the scaffolds.

(h) **Tubular pole scaffolds** are recommended for exterior or interior work for heights up to 200 ft. All scaffold support members are made from galvanized steel tubing fastened together with steel couples or other approved locking devices. Various members may be described as follows:

Posts are vertical supporting members.

Runners are lengthwise horizontal members.

Bearers are supports for the plank platform.

Braces are diagonal members applied lengthwise and crosswise as required.

These members are available in various weights depending on the height and maximum platform load. Post sizes for scaffolds used in masonry work are generally 2 or 2½ in. o.d. Whenever possible, the scaffold should be tied to the building through the window openings. This will greatly reduce the necessity for crosswise bracing.

(i) **Towers.** Material-hoist towers erected outside of buildings are usually constructed of timber or tubular steel sections.

Post sizes for wooden towers will vary from 4 x 4 in. for the top section to 6 x 8 in. for the lower portions as determined by height and cage capacity. Horizontal ties of 1 x 6-in. to 2 x 8-in. material are required at 6- or 8-ft. maximum intervals, with diagonal cross bracing between horizontal ties on all four sides except at loading or unloading platforms. At these openings, additional corner bracing is generally required. Guide rails for cages should be of sound lumber free from knots or other defects and must be kept in perfect alignment at all times.

All hoist towers should be securely anchored to the building or guyed to well buried "dead-men" of adequate size.

The overhead framework of all towers must be of sufficient strength to carry the entire dead and live loads with a safety factor of 5.

Steel tubular towers are extensively used by contractors for hoisting all types of building material. They are easily erected and dismantled and, due to their strength and stability as well as economy, have practically supplanted wooden towers in modern construction. Towers up to 200 ft. in height may be constructed with 2½-in. o.d. tubing. This compares with 6 x 6-in. or 6 x 8-in. timbers required for the lower half of 200 ft.-maximum height wooden towers. Heavy duty tubular steel towers consisting of 3-in. o.d. tubing are used for heights up to 850 ft.

1111. STUCCO AND PLASTER

(a) Exterior Stucco Finish. Brick or tile provide an excellent base for the direct application of portland cement stucco as well as lime and gypsum plaster. In addition to the positive bond between the materials, the walls are remarkably rigid and free from movement due to changes in moisture and temperature conditions. This is an important characteristic of clay masonry construction.

Units intended for use with stucco finish are available in all standard wall thicknesses for single or multiple unit construction. Although dove-tail or grooved finishes are the most common, approved surfaces may be smooth, scored, combed, or roughened in accordance with ASTM specification requirements for load-bearing and non-load-bearing wall tile. Tests conducted at the National Bureau of Standards on the adhesive resistance of the various surface finishes show excellent bond results for all types.

In order to be assured of a permanent stucco finish, the essentials of building construction as required for all kinds of materials must be followed. Footings should be solid and unyielding, and foundation walls should be constructed of proven materials, capable of carrying the sustained loads.

Stucco is one of the oldest and most versatile types of exterior wall finish. Examples exist today which have endured for many years, particularly in the Central European countries. Investigation in these countries indicate, however, that less-dense mixtures are used than in this country and surface scraping is often resorted to in order to remove the rich and fatty surface film. It is noted that the smooth steel trowel or even the wood-float finish may be responsible for surface crazing. These hair cracks are due to shrinkage of the rich surface material and are more apt to occur when a wet mix is used. To prevent crazing, a felt polisher, cork or carpet covered float may be used, which produces a reasonably smooth surface.

Stucco on structural clay load-bearing tile is one of the most economical forms of fireproof wall construction, being acceptable in the 8-in. wall thickness, with interior plaster, for a 4-hr. fire-resistance period when used with incombustible framing members.

1. Recommended Mixes. Mortar for exterior cement stucco or cement plastering should consist of the following proportions, in accordance with present recommendations: One sack of cement to 3 cu. ft. of sand, and approximately 10 lb. of hydrated lime as required for workability.

Dry hydrated lime is added to the cement and thoroughly mixed dry, before spreading over the prepared sand bed. These ingredients are mixed until a uniform color is obtained, approximately ⅔ of the required water is then added, and the remainder as required to any dry spots until a uniform mass of the proper consistency is obtained.

2. Application. All hangers, fasteners, trim, or other fixed supports or projections should be in place previous to the application of any stucco. Flashings must be provided above and below all openings, at parapets, spandrels, and at all other points where water may enter.

Stucco is generally applied in two coats on structural tile walls for a total thickness of not more than ⅝ to ¾ in. Generally the tile surface must be evenly wetted to prevent a rapid loss of moisture from the mortar. Due to the range in absorption of various clay products, experience of the skilled craftsman will best determine the amount of wetting required. In any event

the walls should not be saturated and in colder and damp weather only a light application may be required. On hard, low absorption units no wetting may be necessary.

The first coat should be well troweled to insure proper mechanical bond. It should be doubled back to bring the plaster to the required thickness and brought to a true and even surface by the use of a straight edge. Before the coat has set it should be cross-hatched to insure a strong mechanical key for the finish coat. Plastering should be carried on continuously without allowing the plaster to dry at the edges.

The second or finish coat should be applied not less than seven days after the first coat, and should be from ⅛ to ¼ in. in thickness depending on the type or roughness of final surface texture. If desired, white cement may be substituted for the final coat in place of ordinary portland cement and it may be tinted by adding mineral color pigments to the mixture. Because of the difficulty of obtaining a uniform color when job-mixed, a prepared exterior stucco finish is often used for the finish coat. It is available in white and various popular shades and is especially designed to resist moisture and temperature changes.

3. Curing. After the first coat is applied, it should be kept damp for at least two days and allowed to dry gradually. Before the next coat is applied it must be evenly wetted, but not saturated. This is done by throwing the water from a large brush as the work progresses. The skilled plasterer will use just the right amount of water to obtain the proper workability and maximum adhesion.

The finish coat should also be kept damp for at least two days either by sprinkling or covering with wet burlap or similar material.

Unless adequate precautions are taken to insure proper curing temperature, stucco should not be applied when the temperature is below 32° F.

The following recommendations on the pneumatic application of stucco are quoted from the Report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete:

"(a) Construction utilizing pneumatically applied mortar has been in the hands of a few organizations specializing in this field and utilizing equipment produced by a very limited number of manufacturers. The type of construction has been in use for many years and considerable advance in technique and equipment has been made during that period, but there is still considerable divergence in procedure between the different users. The purpose of this section is to provide a resume of the accepted practice as supplementary to the general specifications.

"(b) The results obtained in pneumatically applying mortar depend to a large extent on the skill of the operator and the work should be done only by experienced men.

"(c) Two types of equipment are available, single or double chamber. The single chamber type is operated intermittently, and is adaptable to small jobs only. The double chamber type which can be operated continuously is the most common type in use.

"(d) The grading of the sand is important in obtaining high strength and density. The sand should be passed through a ⅜-in. sieve and have a fineness modulus of 3.0 or less. Stone sand subject to the same grading limitations as natural sand gives satisfactory results.

"(e) The proportions of cement to sand for various purposes should range from 1 part cement to 3 parts sand, to 1 part cement to 4½ parts sand, in terms of dry and loose volumes. The mortar in place will have a somewhat lower proportion of sand because of the loss due to rebound.

"(f) Control of the water content is important for pneumatically placed mortar in order to obtain proper placement. The water content should be such that a very slight film of water will form on the surface of the applied material. Insufficient water results in dry porous spots and excess water causes low strength and slipping of the mortar.

"(g) The air and water pressure should be maintained uniform. The water pressure should be at least 15 psi higher than the air pressure which should be sufficient to give proper velocity to the material leaving the nozzle. To avoid excessive impact the air pressure should not exceed 75 psi.

"(h) The sand should be neither excessively dry nor wet—about 4 per cent moisture by weight is desirable. Sand and cement should be thoroughly premixed by machine as very little mixing takes place during the application.

"(i) The velocity of the material that leaves the nozzle should be maintained uniform and should be such as to produce a minimum of rebound of the sand. The nozzle should be held between 3 and 4 ft. from the surface being covered and should be kept moving to obtain a uniform coating.

"(j) Special care should be taken in the removal of forms and in the curing to avoid cracking of the thin sections. Placing at temperatures below 50° should not be attempted unless adequate facilities are available for keeping the mortar above 50° during and after placing. The surface to which mortar is applied should be free from frost.

"(k) Shooting strips should be used at corners, edges and on surfaces where necessary to obtain true lines and proper thickness. The surface of the mortar may be 'steel floated' when a very smooth finish is desired.

"(l) The placement equipment should be thoroughly cleaned whenever work is to be stopped for a period in excess of 30 min.

"(m) The position and size of reinforcement where required and the thickness of coating varies with the use of the pneumatically applied mortar and should be within the limitations given below. Square reinforcement bars should not be used."

(Only the limitations affecting stucco on tile, terra cotta, brick and concrete are quoted.)

Use	Reinforcement	Thickness
Stucco or Facing on Tile, Terra Cotta, Brick, and Concrete.	Not necessary except for badly disintegrated surfaces in which case use galvanized welded fabric equal to 0.2 per cent of cross-sectional area of the mortar securely attached to the structure and located at middle of coating.	⅝ in. to 1 in. placed in two layers, second ⅛ in. thick. Screed to proper surface before applying second layer.

(b) Interior Plaster Finish. Since the development of structural clay tile for building purposes, this material has been recognized as standard construction for the application of interior plaster.

If desired, dampproofings consisting of troweled or sprayed asphalt preparations may be used on the inside surfaces of exterior walls before the plaster is applied. This is intended to protect the plaster from contact with moisture which may possibly seep through the walls from leakage or capillarity. These dampproofings do not in any way improve the bond of plaster to the wall but do have sufficient adhesion to provide very satisfactory performance.

Most authorities recommend the use of furred plaster on the interior surfaces of exterior walls, particularly for 8-in. masonry wall construction. The furring may be wood or metal strips fastened to the wall. Lath is then attached to the strips to provide the plaster base or key. It may be wood or expanded metal, plasterboard, or rigid insulation. The furring space increases the insulation value of the wall and prevents possible dampness due to condensation as well as from leakage or capillarity.

1. Types of Plaster. For ordinary plaster the cementitious material is usually gypsum or lime. Portland cement and Keene's cement, a hard-burned gypsum product, are also used, and often required in certain interior areas. Sand is the principal aggregate with the addition of hair or wood fiber in some cases, particularly for scratch coats. These materials are mixed with water to develop the plasticity of the cementitious material and to react chemically in the hardening process.

Light weight aggregate, such as Zonolite or Perlite, is now being used in increasingly greater volume to replace the sand used in ordinary plaster. These materials provide a greater insulating efficiency and increased fire resistance. In addition, the dead air spaces absorb sound and impart a high degree of resistance to cracking due to nailing, shock, or impact. Manufacturers' directions should be carefully followed regarding proportions, materials and methods of application.

2. Recommended Mixes.

Gypsum or hardwall plaster is mixed 1 part gypsum to 2 parts sand by weight for the scratch coat on three-coat work, and 1 part gypsum to 3 parts sand for the brown coat or the base coat for two-coat work.

Wood Fiber Gypsum Plaster is mixed with water only for the scratch coat on lath and mixed one part fibered gypsum to one part sand, by weight, for the brown coat or the base coat on masonry.

Lime Plaster for scratch coat on three-coat work consists of one volume of putty and not more than two and one-half volumes of sand gauged with 10 lb. of Keene's cement per cu. ft. of putty, with sufficient hair or wood-fiber to form a binder. For the brown coat or the base coat of two-coat plaster applications on masonry, three volumes of sand are permitted and the percentage of fiber or hair reduced ⅓ to ½. Where no finish coat is desired the fiber is omitted from the brown coat.

Portland Cement Plaster is mixed and applied as described for exterior stucco finish.

3. Finish Coats. The finish coats for gypsum and lime plaster should be a prepared hard finish applied in accordance with the manufacturers' directions, or a mixture of lime putty and calcined gypsum, or Keene's cement. It generally consists of one part calcined gypsum (plaster of paris), or of Keene's cement, to three parts lime putty by volume. The lime putty should be a stiff mixture of hydrated lime or pulverized quicklime and water. It should be completely slaked and allowed to cool before using. Putty should be

allowed to soak in accordance with lime manufacturers' instructions, and must be kept moist until used.

Keene's cement hard finish is mixed in the proportions of three parts Keene's cement to one part of lime putty, by volume.

4. Application. When plaster is applied directly to the surface of clay masonry walls and partitions, only two-coat work is required. The brown or base coat may be doubled back by applying a thin coat to fill the small depressions and then brought out to the grounds and straightened to a true surface. If a finish coat is used, the base course must be carefully scored to create a bond for adhesion. The finishing coat should be applied after the undercoat has become about dry.

For three-coat work, as required on lath, the scratch coat should be applied with sufficient material and pressure to provide a proper key, and then scratched vertically and horizontally to obtain a rough surface for the brown coat. Where lime plaster is used, the brown coat should be applied only after the scratch coat has thoroughly dried. Where gypsum plaster is used, the brown coat should be applied only after the scratch coat has become thoroughly set, firm and hard.

Keene's cement lime putty finish and the Keene's cement hard finish should be applied over a thoroughly set base coat which is nearly, but not quite, dry. If the base coat has dried out it should be lightly sprayed with a limited amount of water, but not soaked, before the finishing coat is applied.

In general, the finishing coats should be scratched in thoroughly, laid on well, doubled back, and filled out to an even surface. These coatings are allowed to dry for a few minutes and then troweled and brushed to a smooth finish. The total thickness of the finishing coat should be not less than $\frac{1}{16}$ in., nor more than $\frac{1}{8}$ in.

1112. PAINTING

(a) Exterior. Since the natural colors and shades of brick and tile units are both pleasing and permanent, painting is not required on walls constructed of these units except to obtain a special decorative appearance or architectural treatment. Furthermore, paint should not be used as a waterproofing medium unless recommended to seal shrinkage and separation cracks in the mortar or possible capillarity through the joints.

Conclusive tests show that very little dampness, even under severe exposure conditions, will penetrate the clay masonry units. However, incomplete filling of mortar joints or the use of unwetted units particularly in warm weather may provide a path for the penetration of moisture under certain exposure conditions.

Except for the specific purpose described above, painting of structural clay masonry walls is primarily a question of taste and can best be answered by the owner himself. No one should be misled, however, into believing that painting of clay masonry walls adds to the structural qualities of a building. The cost of painting must be charged to appearance alone and cannot be offset by increased permanence or resistance to weather as in the case of frame structures.

Claims made that painted walls are superior to unpainted ones from the standpoint of insulation and heat transmission are too theoretical to warrant serious consideration. It is true that saturated materials have higher coeffi-

cients of conductivity than dry materials, however, clay masonry units are rarely, if ever, saturated in a wall even under the most adverse conditions and heat transmission is relatively unimportant during or immediately following heavy rains. In extremely cold weather or during very hot weather, clay masonry walls are usually dry.

Increases in reflected light and reduction of exterior exposed wall surface temperatures obtained by the use of white paint on red masonry surfaces can be easily verified by test. However, painted masonry walls are difficult to clean and the effectiveness of the painted surface (particularly exterior walls) decreases rapidly with weathering and the accumulation of soot and dirt. A permanent treatment and one less expensive to maintain would be the use of glazed tile or light-colored facing units.

As indicated in Chapter 7, Section 722, exterior coatings on masonry walls which have a high resistance or are impermeable to vapor travel will cause condensation within the walls when the wall temperature falls below the dewpoint. This condensation will tend to saturate the wall and may cause leakage at the interior surfaces. A highly vapor-resistant coating will also prevent the rapid drying of masonry walls which, in the literature on the subject, are frequently referred to as "breathing". Brick and tile walls, particularly when built of high absorption units, dry rapidly following periods of partial saturation due to capillary action which draws the water entrapped in the wall to the face of the units. If this breathing action is retarded or eliminated, water which may enter the wall through openings in the mortar joints will accumulate until the wall approaches saturation. This condition, not only contributes to dampness on interior surfaces but, if the wall is subjected to freezing in a saturated or near saturated state, the disrupting effects of freezing are many times greater than would be the case if the wall were relatively dry.

This is the reason that many brick, which have resisted freezing and thawing for years when exposed in exterior walls, have spalled after one or two years' exposure when painted.

In general, if brick are to be painted, they should have a higher resistance to freezing and thawing than if unpainted, and paints having low resistance to vapor travel are to be preferred.

1. Cement Paint. In addition to the breathing property of cement paint, another reason for a preference over oil paint is that the cement paint is applied to a damp masonry wall.

The following are the recommendations of the Portland Cement Association for the application of cement paint to masonry walls:

"Portland cement paint should be carefully applied in accordance with manufacturers' directions. Surfaces should be damp when cement paint is applied so that even absorption is obtained. High winds, excessive heat and strong sunshine will dry cement paint quickly and render it ineffective as a waterproofing agent unless proper precautions are taken to keep it damp until properly cured. Cement paint should be cured as carefully as concrete. It should be kept damp—not allowed to dry out—until it has set thoroughly. After the first coat has hardened sufficiently to prevent injury to the surface, it should again be wetted down just before applying the second coat. The second coat should also be kept damp until it has thoroughly cured and hardened—preferably for at least 48 hr. after application."

Portland cement paints should not be used over old coats of oil paint, whitewash or casein paints.

2. Oil Paints. Before oil paints are applied to new masonry, the walls should be thoroughly dried out and cleaned of all dirt and mortar particles. If oil paint is desired for any reason on new masonry within 3 months after construction, it is usually necessary to apply a wash coat of zinc sulphate solution (2 lb. to a gallon of water) to neutralize the alkali in mortar joints. This treatment, however, is not always completely effective, particularly if moisture finds its way into the wall. In any case the paint manufacturers' directions should be carefully followed since some oil paints can be applied over a zinc sulphate wash while others cannot.

If there is any efflorescence on the wall, it should be thoroughly removed by brushing while dry. It should then be washed with clean water and then washed with a 10 per cent solution of muriatic acid, after which the wall should be washed again with clean water.

In order to secure satisfactory results, the masonry should receive three coats of paint—a priming coat or first coat, a body or second coat and a finishing or third coat. At least four or five days should be allowed between coats. A typical primer coat consists of exterior spar varnish containing an equivalent volume of house paint or color in oil.

Many paints are produced expressly for masonry surfaces and the application, in any event, should be in accordance with the manufacturers' directions.

A word of caution, however, is justified regarding the claims for highly advertised so called "plastic paints". Tests conducted by the National Paint, Varnish and Lacquer Association and reported in Circular No. 701, indicate that "most of them appear to be no better than, and, in some instances, not so good as regular moderately priced trade sales items."

(b) Interior Paint Finish. Painted finishes are sometimes specified for the interior masonry surface of exterior walls and for unplastered partitions of structural clay tile. Where decorative finishes of this type are desired, the natural smooth surface of clay masonry is particularly suitable for painting. To obtain best results, the surface porosity must be taken into consideration by the use of special recommended priming coats, particularly when using oil-base paints. Manufacturers' directions should be carefully followed as required for the various types of paint, number of coats and methods of application.

If oil paint is used on new masonry construction (less than 3 months old), the walls should be neutralized with a zinc sulphate solution as described above for exterior surfaces.

Cement-base paints are satisfactory for interior masonry surfaces, also casein paints when used on dry interior walls.

1113. REPAIR AND MAINTENANCE

(a) General. Properly constructed clay masonry walls are remarkably free of costly repair and maintenance. When required, the repair of existing masonry is often more difficult and costly than proper construction of new

work. Care in the selection and use of mortar and adequate flashing and tooling of joints will probably add only a small amount to the initial cost but will insure a low maintenance overhead throughout the life of the property.

(b) Tuck-pointing. Where the mortar joints have softened or disintegrated or large cracks are noted, it will be readily apparent that protective measures must be taken to correct or prevent leaky walls.

This is done by cutting out all loose or disintegrated material for a depth of at least ½ in. and repointing or filling with proper mortar. If the work is being done to correct leakage, all joints should be cut out in the affected area as it may be very difficult in some cases to determine the defective joints by visual inspection. If no leakage has been noted and the repointing is being done as maintenance work, it is necessary to remove only the defective mortar.

When the cutting is completed all dust and loose material must be removed by brushing or, preferably, with a water jet. If water is used in cleaning the dust from the joints, no additional wetting may be required. The repointing should not follow immediately after the joints are washed and little if any wetting will be necessary when the walls are constructed of low absorption units.

Recommended mortars for tuck-pointing are described in Chapter 5. As indicated, the natural tendency to use a rich mortar must be avoided. It should never be denser than the original mortar and preferably pre-hydrated by mixing at least 2 hr. before using, with only a portion of the required mixing water. At the end of the curing period the mortar must be reworked, adding the remaining water. This greatly improves the workability and much of the initial shrinkage is eliminated. The mortar should then be packed in tightly in thin layers and finally tooled to a smooth compact concave surface.

(c) Waterproofing. When the mortar cracks and openings are small, a two-coat application of cement-sand grout brushed vigorously into the mortar joints will provide an effective waterproofing method. A typical recommended mixture consists of equal parts, by volume, of portland cement and dry sand passing a No. 30 sieve, with ¼ part of cement, by volume, replaced by limestone flour, powdered flint or fine hydrated lime. The joints should be thoroughly wetted before applying the grout.

(d) Flashing. The omission of flashing, the use of an improper type or good flashing incorrectly placed is often responsible for the most serious masonry problems. Unflashed brick and cast or cut-stone sills, projecting courses, and particularly copings, generally result in leakage or, at least, disfigured walls caused by efflorescence. The only proper solution is an expensive repair job which requires removing the brick or stone and placing suitable flashing around and under it. When continuous flashing is required in existing walls at spandrels or other locations, it can be placed by removing alternate masonry sections in widths up to 2 or 3 ft. After the flashing is placed and masonry properly aged, the intermediate pier sections can be removed and the flashing completed.

(e) Caulking. Improper caulking is often responsible for the most serious water leakage around door and window frames. If the caulking was completely omitted, this is easily corrected by filling all cracks with a good elastic caulking compound placed with a pressure gun. On the other hand, if the original

caulking has cracked, peeled or separated, it should be removed and replaced with new compound. Unless proper pressure is used only a thin film of caulking compound will be placed. Even with good material, this will soon become ineffective. Thin films should be removed and properly replaced before serious damage is caused.

CHAPTER 12

BONDS AND PATTERNS

1201. ACKNOWLEDGMENT

In 1915 the Hydraulic Press Brick Company of St. Louis, Missouri, published the booklet, "Bonds and Mortars in the Wall of Brick," which contains a very comprehensive discussion of the bonds and ornamental patterns which can be obtained in brickwork. This publication has been reprinted four times and some 25,000 copies have been distributed to architects and others. It still remains, however, one of the outstanding publications on pattern bonds and the discussion of this subject is reproduced in its entirety.

The author expresses his appreciation to the Hydraulic Press Brick Company and particularly to George Bass, Chairman of the Board of Directors, and L. S. Meyer, President, for permission to reprint this material.

1202. DEFINITIONS

Masonry bond may be defined as the method by which each brick in the wall is so placed that the entire wall, by the overlapping of the individual brick upon each other, forms one solid mass throughout its length and breadth. The brick laid with the length of the wall, or the stretchers as they are called, secure by their overlap longitudinal bonding strength, while those laid across the width of the wall, or the headers, bond the wall transversely.

The term bond is also applied to the adhesion of mortar to brick and to steel reinforcing. In masonry walls where all interior joints are filled solidly with mortar or grout, such as reinforced or grouted brick masonry walls, masonry headers are frequently eliminated and the adhesion or bond between mortar and brick is relied upon to bind the parts of the walls together, providing increased lateral strength. Numerous tests indicate that for such constructions the strength of mortar bond is more than adequate for this purpose.

Masonry bond is based on either one or two methods of bonding, both of which systematically include headers with the stretchers throughout the courses. The first is known as English Bond, and consists of alternating courses of headers and stretchers; the second is the Flemish Bond, consisting of alternating headers and stretchers in every course, so arranged that the headers and stretchers in every other course, respectively, appear in vertical lines. All ornamental bonds are simply variations of these two fundamental forms.

It is essential, however, that the designer of ornamental brickwork should be cautioned not to confuse bond and pattern. Bond refers primarily to the arrangement of the brick as they overlap each other from course to

course. It is true, bond may be frequently used to make various patterns by this arrangement; but, in the strict sense of the term, pattern refers to the change, or the varied arrangement, of the brick texture or color used in the facing; so that in this way it may be possible to secure many patterns in identically the same bond. Pattern may also be produced by the handling of the mortar joint, or by the projection or recession of certain brick from the plane of the wall—a form of pattern used especially in the Moorish and Spanish brickwork.

1203. CLASSIFICATIONS OF BONDS

Running or Stretcher Bond (Diagram 1) consists entirely of stretchers overlapping each other one half brick, that is, breaking joint evenly, with the vertical joints in alternate courses forming perpendicular lines. This bond is suitable for use in wall facing which must be tied to the backing by mortar bond or other means. The use of metal wall ties and the method of clipping the interior corners of the facing brick to permit the insertion of diagonal headers into the backing are illustrated in Diagram 2; so also

Diagram 1

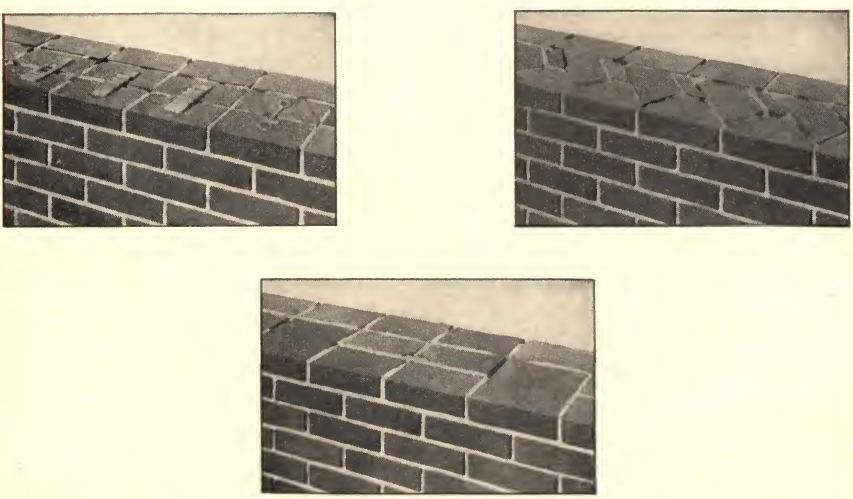


Diagram 2

is the use of a bonding brick, made of double width for this special purpose. To provide the transverse strength of this bond, a header—sometimes a Flemish—course is introduced at regular intervals, generally every sixth or eighth course, resulting in what is known as Common Bond (Diagram 3 shown with three intervening courses), which affords a perfectly satisfactory bonding strength in the wall transversely as well as longitudinally.

Diagram 3

Another form of Running Bond is given in Diagram 4. Here the stretchers overlap only a quarter brick, or are crossed one-half instead of being wholly crossed as in Diagram 1. This bond is very rarely used for any large surface, but frequently occurs in two or three courses separated by a Flemish or a header course, approaching in its nature the Common Bond.

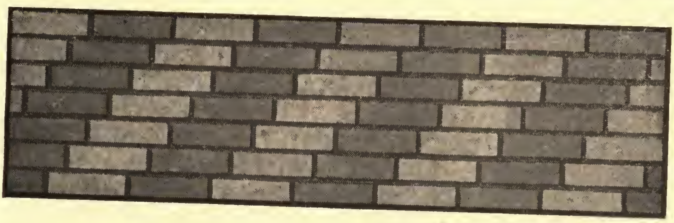


Diagram 4

Diagram 5 shows a running Header Bond worked by the brick texture or color as a zigzag. In Diagram 6 we have headers laid without any bond at all in vertical lines, producing a reticulated appearance and forming what is known as Checker-Board Bond. Although it is sometimes used in wall surfaces, it is merely ornamental and does not strictly come under the definition of bond. It should properly be used only in panels or contained areas.

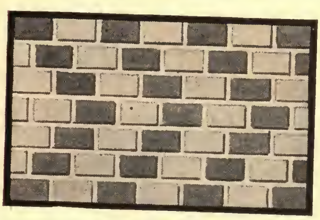


Diagram 5

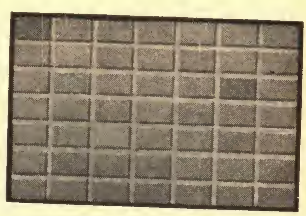


Diagram 6

English Bond (Diagram 7), already mentioned as one of the two basic methods of bonding, consists of headers centered on the stretchers which

lie in vertical lines. The tinting of the diagram shows two possible patterns which may be obtained by change in color or texture of the brick. English Bond presents serious practical difficulties in case two headers with the mortar joint, as formerly frequently happened, occupy a greater space than the length of the stretcher, thus making it exceedingly difficult to secure the desired alignment in the vertical joints. This situation has now largely been eliminated due to the adoption by the industry of modular sizes for brick in which the thickness of the mortar joint is standardized for various grades of brick and the standard width of two headers and one mortar joint equals the length of one stretcher.

Diagram 7

English Cross Bond (Diagram 8), referred to by some builders as Dutch or Dutch Cross Bond, is a modification of English Bond in which the stretchers are crossed; that is, break joint evenly in the successive stretcher courses. Diagrams 7 and 8 are drawn so as to show two headers with the joint as being exactly equal in length to the stretcher. Diagram 8 shows two pattern arrangements which may be made in English Cross Bond, dependent upon handling color or texture.

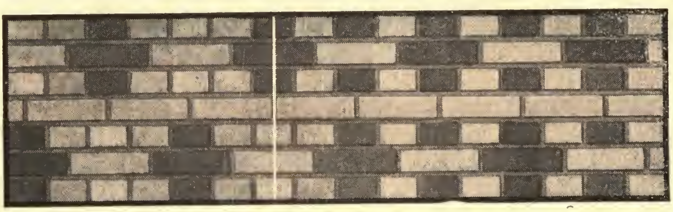


Diagram 8

Flemish Bond (Diagram 9), already mentioned as the second basic method of bonding, consists of alternating headers and stretchers in all the courses of the wall, and these are known as Flemish courses. There are two legitimate methods of starting the corner in this bond, both of which are frequently used on the same work. The left end of the diagram shows the

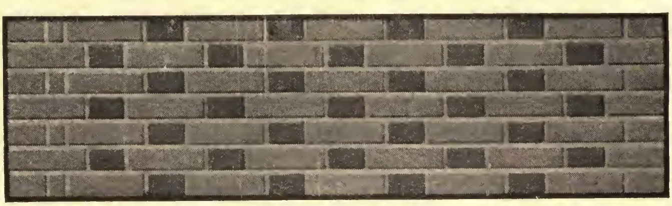


Diagram 9

use of a quarter-brick, or "queen" closer, known as the "clip." The right end shows the use of the three-quarter brick, or "king" closer. There should be no variation in color, however, between the clip as shown on the left-hand edge and the general wall color of the course. Pattern in this bond should be made only by the headers. The closer at the corners should never be included as part of the pattern. It should be stated in passing that the brick designer must exercise great care in the use of his quarter-brick closer or clip in beginning or ending his courses at corners or edges of openings. He may without scruple begin or end his course with a three-quarter brick if necessary, but in case the clip is needed to complete the bond, it should never be permitted to take the corner. Its best position is next the corner brick, as seen in the left-hand edge of the diagram.

Flemish Bond may be modified by doubling the stretchers in every course (Diagram 10) and centering the headers over the stretcher joints, which are always concealed or "blind"—in this particular alone differing from a Double-Stretcher Garden Wall Bond (see under Diagram 16).

Flemish Bond with its variations is the basis of most pattern bond, which largely depends upon crossing the simple Flemish Bond by first introducing variously crossed stretcher courses between the Flemish courses and then shifting the Flemish header in one of several different ways, or allowing it to remain in a vertical line.

Diagram 10

Thus in Diagram 11 we have the simplest form of Flemish Cross Bond which consists of alternating Flemish and stretcher courses with the headers in vertical lines and the stretcher courses crossed. In Diagram 12 we have the same arrangement of crossed stretcher courses, but the Flemish header departs from the vertical line by being shifted back and forth its width. This bond is the beginning of all diagonal pattern bonds, which owe their variation chiefly to the number and treatment of intervening stretcher courses, and to the way in which the header is shifted. In Diagram 13 a Flemish course alternates with two stretcher courses which have an overlap of a quarter brick and reverse the diagonal direction of their vertical joints after

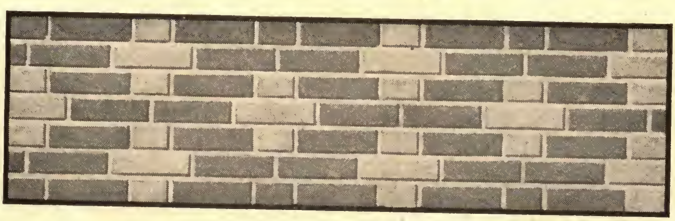


Diagram 11

Diagram 12

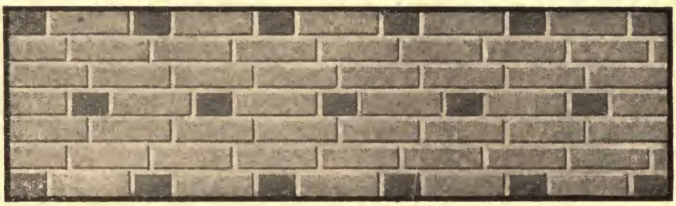


Diagram 13

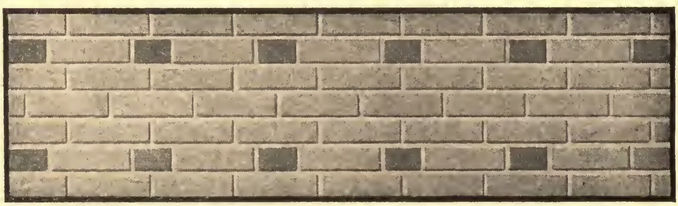


Diagram 14

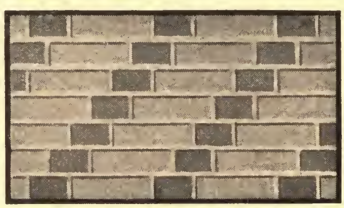


Diagram 15

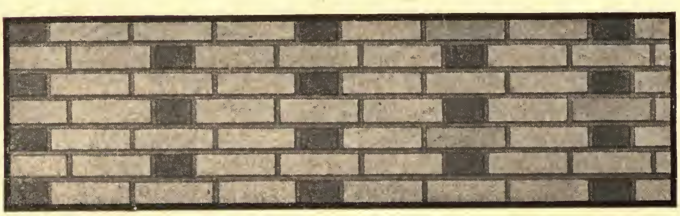


Diagram 16

every Flemish course, while the header is shifted back and forth three-quarters of a brick.

Diagram 14 represents a bond in which Flemish courses alternate with groups of three stretcher courses. This is a very satisfactory bond for average brickwork, as the headers are frequent enough to tie sufficiently the facing to the backing brick, and the work can easily be laid out so as to fit average building conditions without serious trouble (see under Diagram 4 and Diagram 3). Diagram 15 shows a Flemish Spiral Bond, having the Flemish courses laid out so that the headers break joint over each other and form diagonal bands on the face of the wall—a bond that is frequently used for stair-towers and chimneys.

In Diagram 16 we have Garden Wall Bond, which was originally used in 8-in. garden walls. Its value lies in its longitudinal strength, with sufficient transverse bonding secured by a symetrical placing of the headers. By this arrangement a wall is laid in which both faces present a like bond surface. The diagram shows the original form of this bond, consisting properly of three stretchers alternating with a header in each course, although it is sometimes laid with two stretchers and a header—then designated as Double-Stretcher Garden Wall Bond—in which case it forms the basis of Double-Stretcher Flemish Bond as given in Diagram 10. Garden Wall Bond may also be laid with four or even five stretchers between the headers.

Diagram 17 is a representation of Garden Wall Cross Bond, which consists of Garden Wall courses alternating with stretcher courses crossed. One form of pattern frequently used in this bond is indicated.

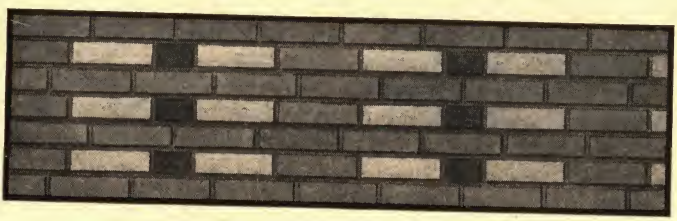


Diagram 17

1204. BOND PATTERN UNITS

Diagram 18, which is an adaptation of the unit system used by Gilbreth, represents the various units or "eyes" upon which all diagonal bonds are based. Beginning with Unit I, which is composed of a stretcher with a header centered above and below it, each succeeding unit is formed by extending every course of the preceding unit the width of a header, always centering the courses on the middle course regarded as the horizontal axis of the unit, and terminating the whole above and below by a header.

As a result the units, however far they may be carried out, always present exact mathematical proportions and bear a definite relation to each other. The serial number of any particular unit may at once be known by subtracting one from its number of courses and dividing by two; or, more simply, by counting the number of courses either above or below the horizontal axis. Conversely, the number of courses in any given unit may be known by doubling its serial number and adding one. Thus if we

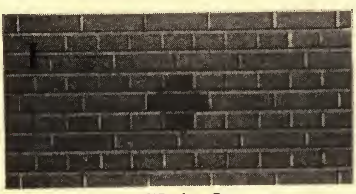
discovered in a brick wall a unit of nineteen courses, nine courses on either side of the horizontal axis, we should know that it was Unit IX; or if we wished to use Unit IX, we should always be obliged to have space for nineteen courses; and so on.

It is interesting to note further that the units may also be recognized by their horizontal axes, which in odd-numbering units are always composed entirely of stretchers, while in even-numbered units they always carry one, and only one, header, set as near their center as possible. The serial number of an even-numbered unit is double the number of stretchers in its axis, while that of an odd-numbered unit is one less than double the number of its axial stretchers. Thus if we see a unit with a horizontal axis of four stretchers only, we may be sure that it is odd-numbered Unit VII; but if it has four stretchers and a header, we know that it is the even numbered Unit VIII.

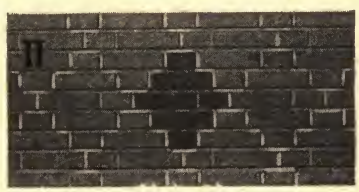
With Unit IV there begin to appear units within units. While the header, crossed by vertical stretcher joints, which appears at the center of Unit IV is not strictly a unit in our sense of the term, it is nevertheless the primary unit of all, as the smallest normal element in brickwork. Unit I clearly comes to view as the center of Unit V; Unit II appears in VI; Unit III in VII; and so on. It is by the treatment of these units, each of which in itself is a bond pattern, that various patterns may be worked out on the surface of the wall by the proper handling of the color tones and textures in the brick, or of the mortar joints.

The units may be made to join, or "butt," each other vertically and horizontally; or they may be separated by introducing between them one or more courses above and below, or variously arranged rows of brick in a general vertical direction on the side, as may be seen in the following diagrams. When separated, the units are said to be surrounded by horizontal and vertical borders. And much of the artistic value of the pattern will depend upon the skill and taste with which these borders are worked out.

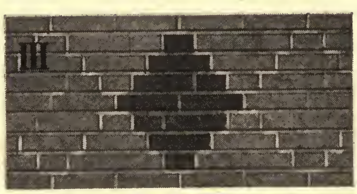
The designer in brickwork is urged to remember that the use of pattern bonds obligates him to pay the strictest and most thoughtful attention to the beginning and ending of the pattern, either at the bottom or top of the structure, or on piers as they occur separately or between windows. He must first decide on a unit which is suitable to the size of the panel to be covered,



Unit I

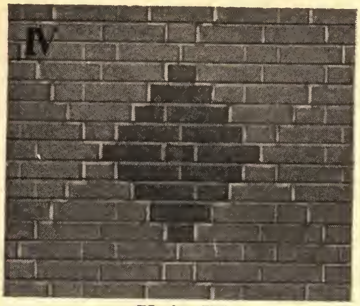


Unit II

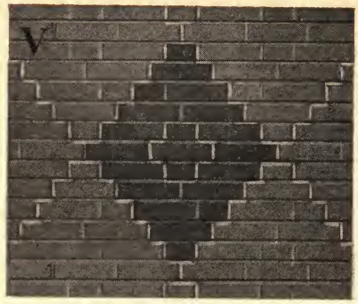


Unit III

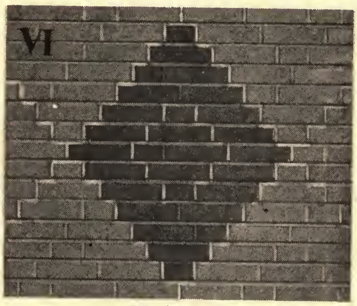
Diagram 18



Unit IV

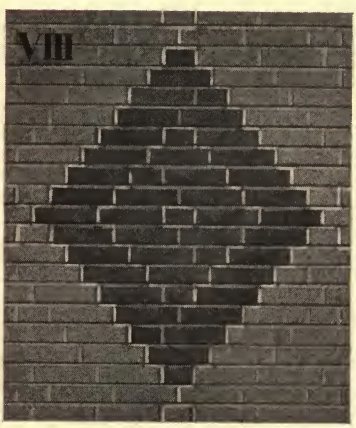


Unit V

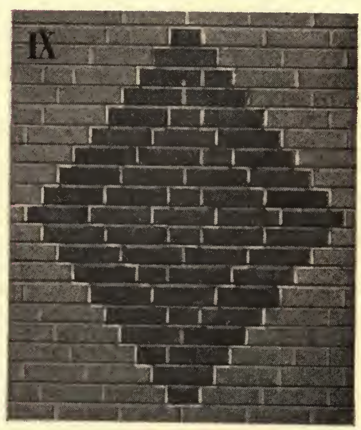


Unit VI

Unit VII



Unit VIII



Unit IX

Diagram 18—(Continued)

and then exactly center it upon the panel, so that his pattern may end in a symmetrical manner, both laterally and vertically. In order to secure vertical symmetry the panel must always have an odd number of courses, that is, an even number on each side of the median line.

1205. BOND UNITS IN PATTERN

The accompanying diagrams offer a few suggestions of the way to handle the units, and to treat the color tones and textures of the brick in designing patterns.

Diagrams 19, 20 and 21 are readily seen to be examples of Unit I, which, if brought out in the design, always presents the appearance of a

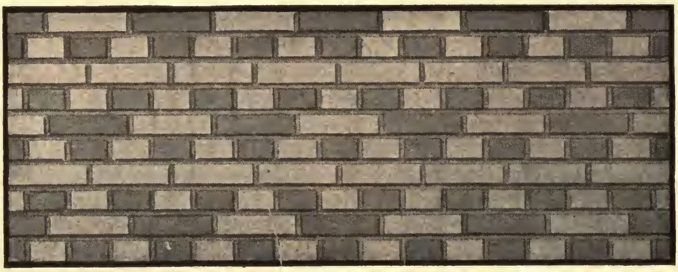


Diagram 19

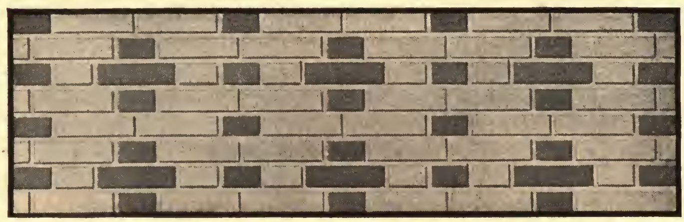


Diagram 20

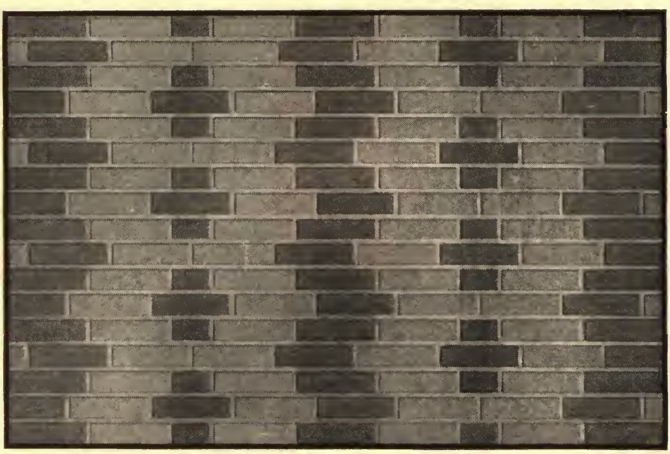


Diagram 21

St. George's or Greek cross. Diagram 19 is, in bond, identical with Diagram 8, or English Cross Bond, and differs from it only by the treatment of the colors in the brick, so arranged as to veil the definition of the units. By comparing the two, it will be seen what different patterns can be woven into the same bond. Diagram 20 is a sort of Garden Wall Bond with the units and certain headers in vertical lines brought out by heightened tones in the color or texture of the brick. In Diagram 21, consisting of alternating crossed stretcher and Garden Wall courses, the unit is also highly accentuated and surrounded by a vertical and horizontal border, but is accompanied by a vertical zigzag of stretchers instead of a vertical line of headers.

Diagram 22

Diagram 23

In Diagrams 22, 23 and 24 are shown varied treatments of Unit II. Diagram 22, which is a modification of Flemish Bond as seen in Diagram 9, presents a wall surface composed entirely of these units completely dovetailed. Here we have an excellent illustration of the distinction between bond units, as such, and pattern. The bond inevitably works out the bond units, and these may be of uniform color or texture throughout the wall; or, as here, brought out by color or texture treatment into distinct pattern units, which butt horizontally and are separated vertically by a header-stretcher border. Diagram 23 is a Garden Wall Bond with the units in vertical lines; while Diagram 24 is a Double-Stretcher Garden Wall Bond with the units in diagonal lines. In both there is a horizontal and vertical stretcher border about the units.

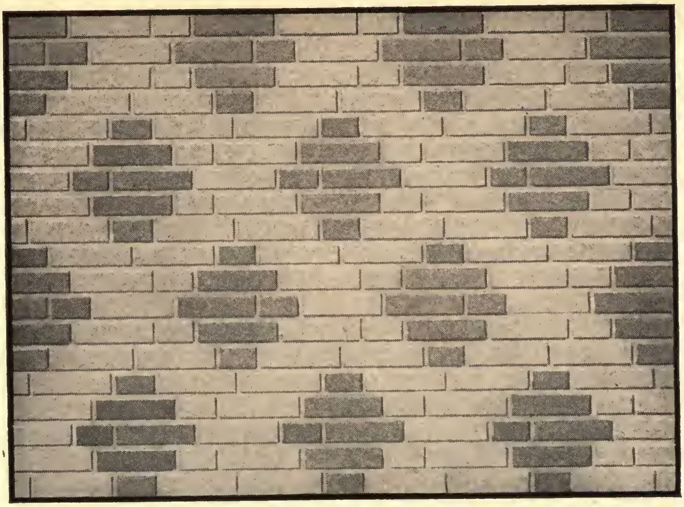


Diagram 24

Diagrams 25, 26, 27 and 28 present a variety of design based on Unit III. Diagram 25 shows a bond of stretcher courses, crossed, alternating with courses of two headers and a stretcher, in which the bond and pattern units have the same dovetailed arrangement as in Diagram 22. Diagram 26 is the same bond as the preceding except that every sixth course is entirely of headers, flanked by uncrossed stretchers. Here, as before, the pattern units butt horizontally but, instead of lying vertically separated by a stretcher course, are set in dovetail fashion and separated vertically by a zigzag line of stretchers and headers.

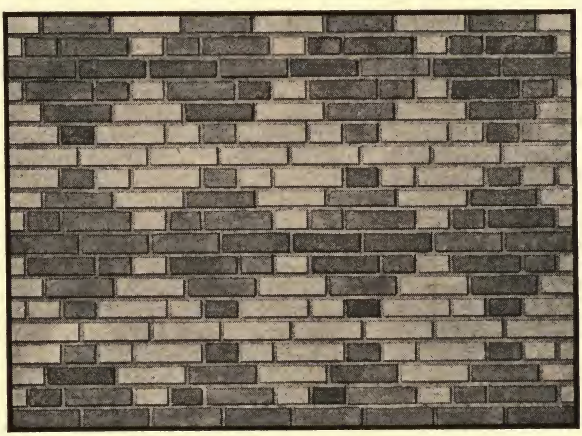


Diagram 25

Diagram 27 presents a very mixed bond in which Flemish and stretcher courses are intermingled regularly with courses of alternating stretchers and four-header groups. The units, deeply dovetailed, are separated horizontally by header and vertically by stretcher borders; and it is interesting to note

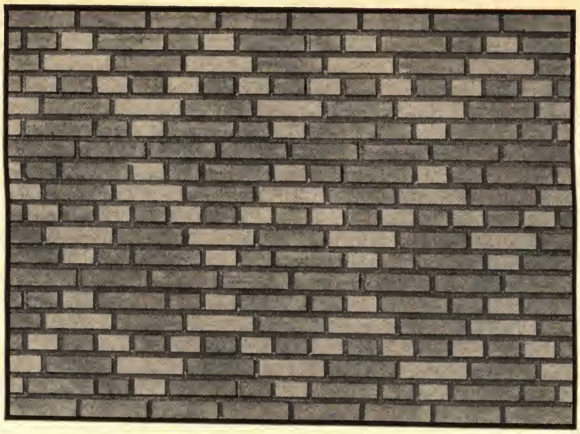


Diagram 26

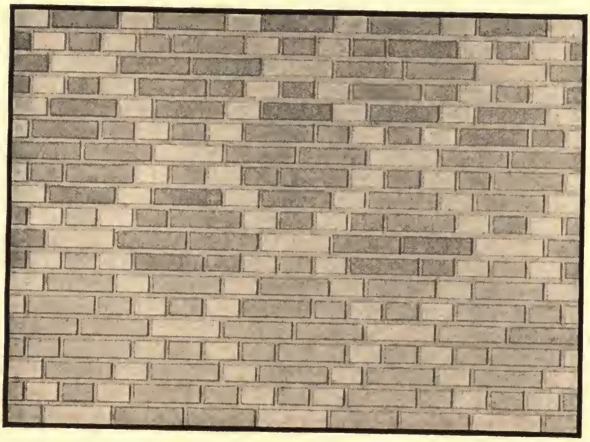


Diagram 27

that the stretcher courses are so set as to form the axial line of one horizontal row of units while serving as the horizontal borders of the new row of units.

The pattern in Diagram 28, worked on a bond of alternating Flemish courses and stretcher courses, crossed, shows the units separated by vertical and horizontal stretcher borders that sweep in great interlaced diagonal bands up and down the surface of the wall. Nothing could show better than this diagram how really simple is the secret of working out these seemingly complex figures. Once having crossed the alternating stretcher courses, that is, shifted them half a brick each time, it is only a matter of attending to the method of shifting the Flemish courses by watching the movement of the header. Beginning for convenience with the fourth course, because in this diagram the first full unit begins there, it is seen that the header shifts its own width three times to the right and then three times to the left, and so on up the entire wall. It will also be seen that the headers rest alternately on stretchers and stretcher cross-joints, and that, with all the shifting, they never depart from this original position.

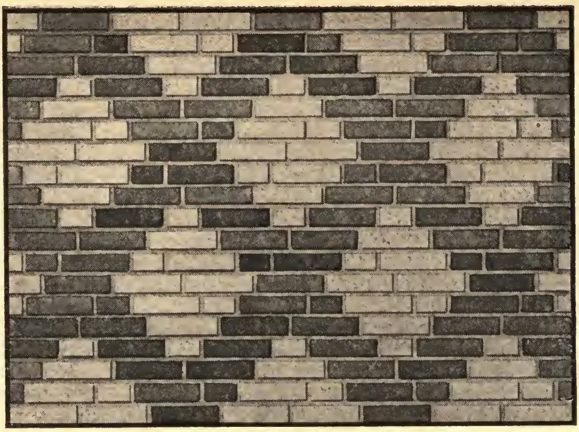


Diagram 28

Diagrams 29, 30, 31, 32 and 33 furnish beautiful examples of Unit IV. Diagram 29 is a Double-Stretcher Garden Wall Bond showing the same arrangement of units as in Diagram 25. And yet aside from the difference in the size of the units employed, there is a striking difference in their appearance when viewed in their relation to the texture of the whole wall surface. In the first instance, the smaller units, with but one distinction of color, are woven together into a compact wall texture. In the second, the larger units, which would be too heavy if thus left solid masses of color, are enlivened by luminous points in their centers, the dark spots giving as much life to the light units as the light spots do to the dark units. Thus the wall is interlaced as a beautiful fabric and presents the appearance of lightness and vivacity.

Diagram 30 shows a Garden Wall Bond with the units set in dovetailed fashion but surrounded by a stretcher border.

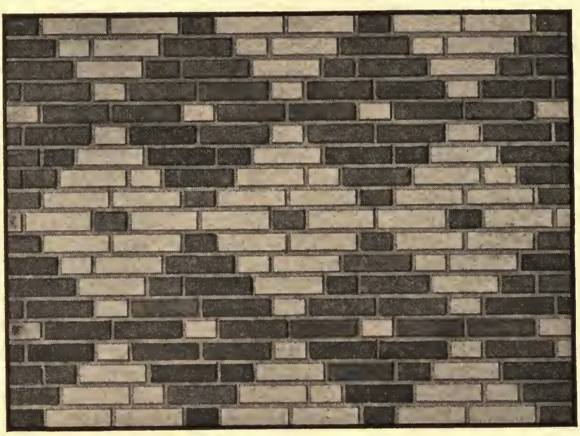


Diagram 29

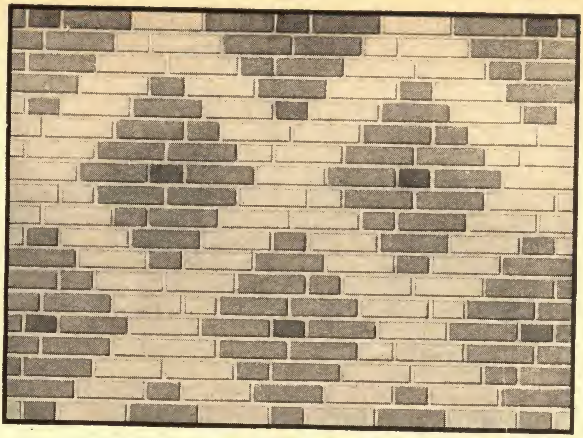


Diagram 30

Diagram 31, a Four-Stretcher Garden Wall Bond, has the units more deeply dovetailed than they are in Diagram 30, resulting in their being thrust apart horizontally by two stretchers instead of one. They also show a horizontal and vertical stretcher border, and are much enhanced in value by the bright spot in their centers. Diagram 32, a very mixed bond, shows the dovetailed units separated by header borders which form interlacing diagonal lines on the surface of the wall; while Diagram 33, also a very mixed bond, presents in like manner the units surrounded by headers but widely separated by double-stretcher borders. By a little study, both the diagrams last named may be seen as presenting Unit VI—merely outlined by the headers—enclosing Unit IV. In the one case, the units overlap both vertically and horizontally; in the other, they stand out quite alone.

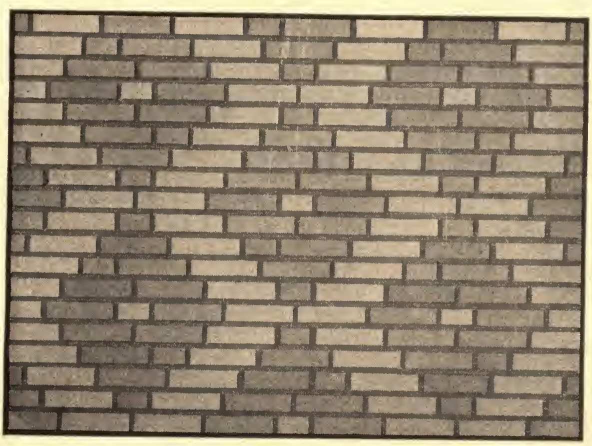


Diagram 31

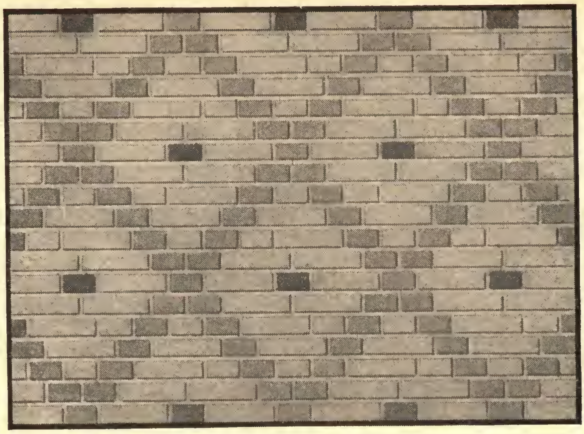


Diagram 32

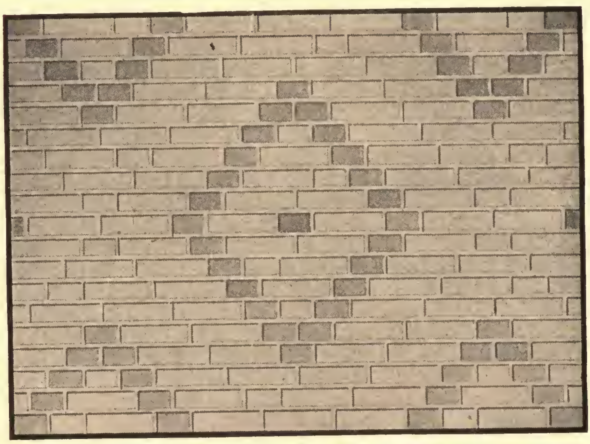


Diagram 33

Diagram 34, a mixed bond, shows Unit V. Here the units, holding in their centers Unit I, are set in exactly diagonal lines and bordered vertically and horizontally by stretchers; while Diagram 35 presents a Four-Stretcher Garden Wall Bond on which is designed Unit VIII, containing Unit IV, distinguished from each other by color tone. The dovetailed units are separated by a horizontally zigzag line of stretchers.

Diagram 36, on the left side, worked on a bond of alternating Double-Stretcher Garden Wall and stretcher courses, crossed, presents an appearance similar to that of Diagram 35, but does so by the use of Unit IX enclosing Unit V, which in turn bears at its center Unit I, all of them brought out by a difference in color. On the right side, by a change of bond, the contained Unit V is made up of Unit I surrounded by like units.

In leaving this subject, it may be well to observe that the choice of a bond unit and the way in which such bond units are to be distributed on the wall surface, as well as the manner of treating them in color or texture,

Diagram 34

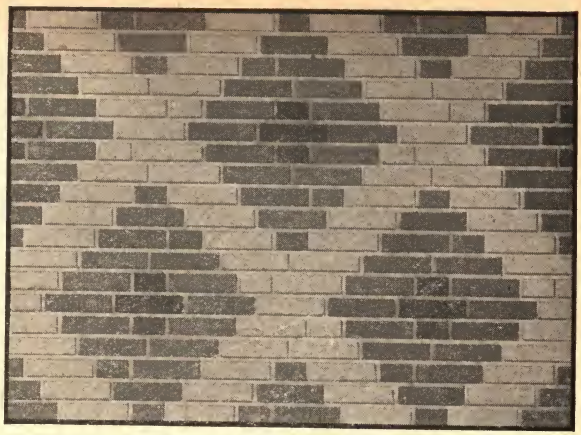


Diagram 35

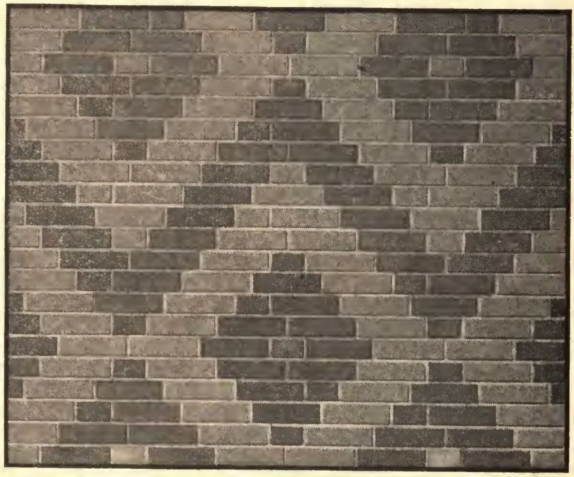
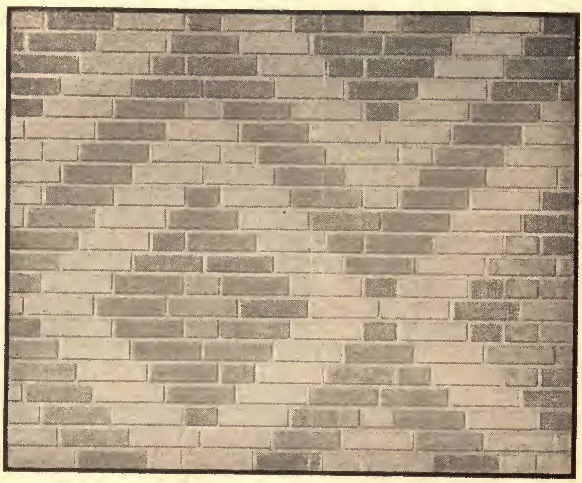


Diagram 36



are matters open to the widest divergence of individual tastes. One designer may be inclined to strong contrasts, while another may treat them with the utmost reserve. But in every case the one aim should be to weave the fabric of the wall in such a way as to make evident its fitness both to the nature of the structure and to its surroundings, natural and artificial.

The subject of bond, however, can hardly be dismissed without a word, and a diagram or two, on paving or panelling bonds. They may be illustrated in a few typical forms. Diagrams A and B show a Herring Bone pattern which may be laid with the brick flat or on edge. Diagrams C and D represent a Basket pattern in its two forms, that is, laid flat or on edge. Diagram E is a Basket pattern laid flat separated by borders laid on edge; while

Diagram A

Diagram B

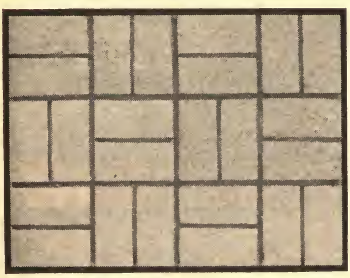


Diagram C

Diagram D

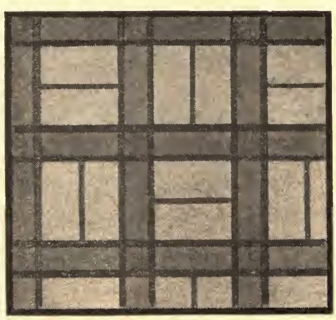


Diagram E

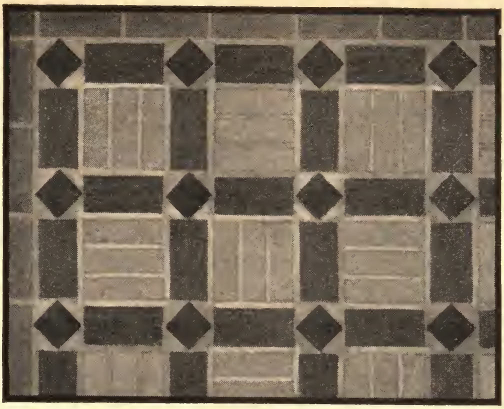


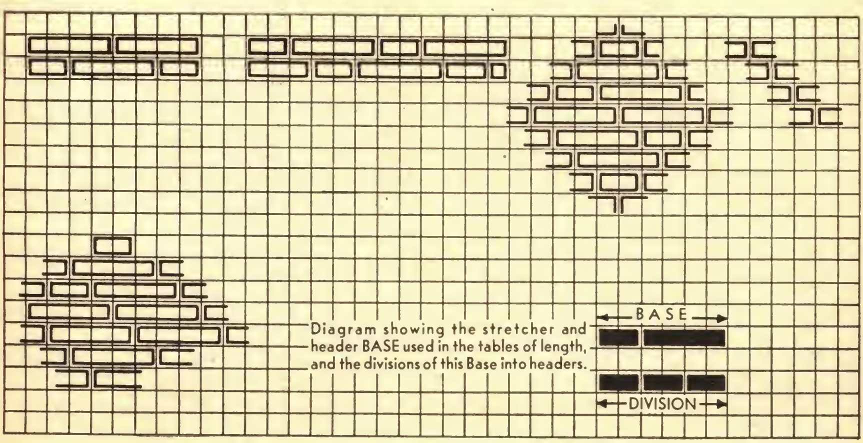
Diagram F

Diagram F shows a Basket pattern laid on the edge separated by borders on the flat.

1206. LAYOUT

The bonds and patterns here illustrated are meant to serve as helpful suggestions to the designer in brickwork; his ingenuity and taste may lead to any number of possibilities along the same line. While the methods of bonding, when once a bond is chosen, are strictly governed by mechanical rules, the pattern schemes, a few of which have been presented here, are a matter for the individual taste of the architect or the prospective builder. These diagrams are by no means intended to dictate what may or may not be the true values of color tones in any given bond, of the blendings of light and shade or the contrasts of color and texture in brickwork, but merely as suggestive hints for pattern design.

At the same time, an underlying principle is involved in what has been thus suggestively presented. It will be readily understood that the smaller units, which are worked into patterns of finer texture and quieter shadings,



Bond Diagram

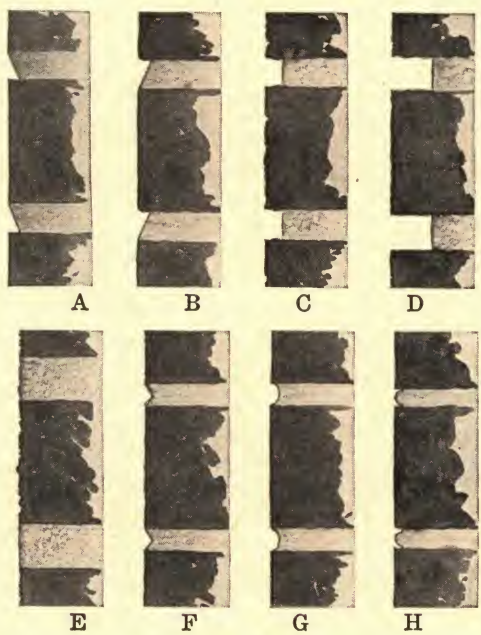
are more appropriate for wall expanses of limited area, while the bolder outlines and heightened contrasts of the larger figures are more suitable for large sweeping wall surfaces.

The various bonds previously shown may be rapidly and easily laid out by the construction of a bond diagram at the scale of the drawing with which it is intended to be used as indicated in the Bond Diagram.

Most diagonal bonds cross at one-quarter brick intervals and if it is essential that the bond finish the same at top and bottom of a panel or pier, an odd number of courses is required. Joints should in all cases be laid out from the center lines—both vertical and horizontal. This will produce similar bonds at the sides, tops and bottoms of the brick surfaces.

On ¼-in. scale drawings the single line will represent the joint, but on the larger scale or details drawings showing joints the simplest method is to use the horizontal line for the under side of the brick and the vertical line as the right-hand edge of the brick—taking off the width of the joint below and to the right of the brick units.

The diagram in the lower right-hand corner of the sheet indicates the base measurements of the horizontal scales, as these are figured on a dimension of one stretcher, one header and two vertical joints equaling the scale base.

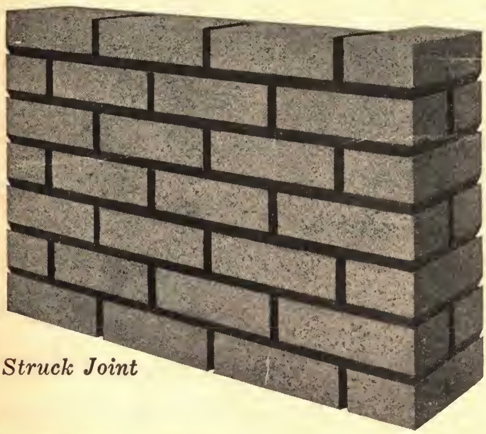


1207. MORTAR JOINTS

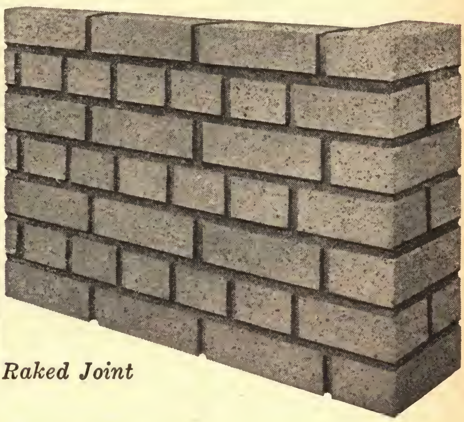
The usual mortar joints in good brickwork are indicated in accompanying cross-section sketches and photographic reproductions. Joints A and B are trowel-struck joints, and are usually made by the bricklayer as the work progresses, being the common jointing in ordinary brickwork. As American mechanics usually work from the inside of the wall, joint A is the easier joint to strike, while joint B, the so-called weathered joint, requires more care as the trowel has to be worked from below. But this

form of joint is the better able to shed the water and is the more permanent joint of the two.

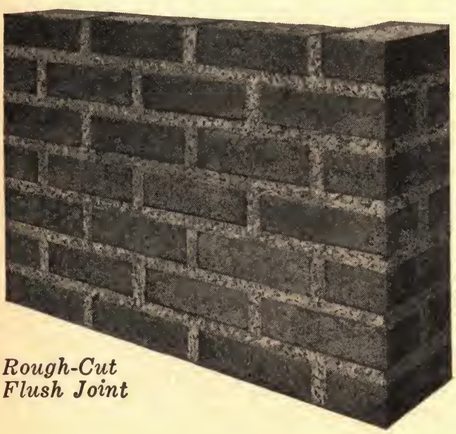
Joint C is a raked joint, made by removing the surface of the mortar, while it is still soft, with a convenient tool. Joint D shows a set-back, or stripped, joint which is made by laying wooden strips on the top of each course and filling up with mortar behind these strips, bedding the brick on the top of the strip which is removed when the mortar is sufficiently hard to sustain the weight of the brick. While the joint stripping adds considerably to the expense, it accomplishes the result of having the bottom edge of the brick on a level line, prevents the smearing of the face with mortar during the course of erection, and generally tends to equalize the horizontal joint. Both the raked and the set-back joint have a tendency to darken the appearance on the wall, owing to the deep shadow which the joint makes on the surface. These joints are very effective and bring out with great distinctness any pattern with which they may be used. They are, however, difficult to make watertight and are not recommended in locations subject to exposures characterized by heavy rains accompanied by high winds unless unusual precautions are taken to prevent wall leakage.



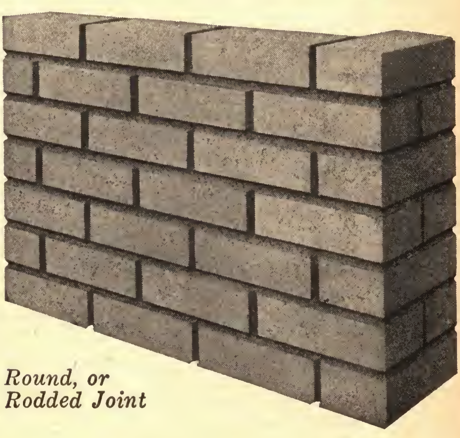
Struck Joint



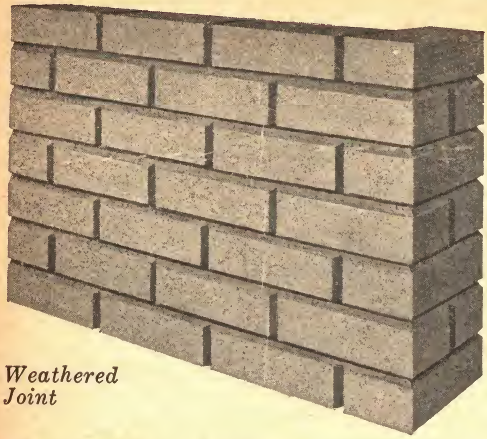
Raked Joint



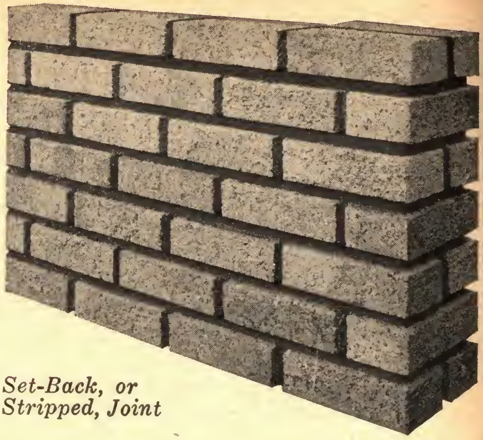
Rough-Cut Flush Joint



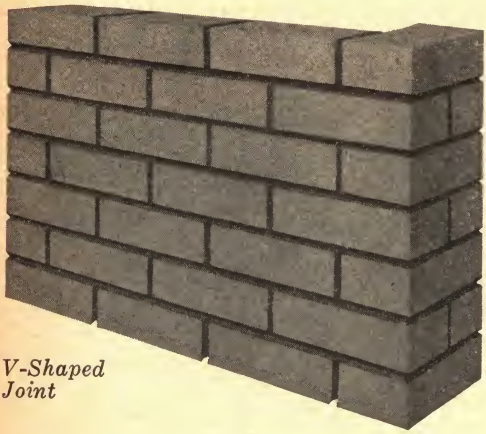
Round, or Rodded Joint



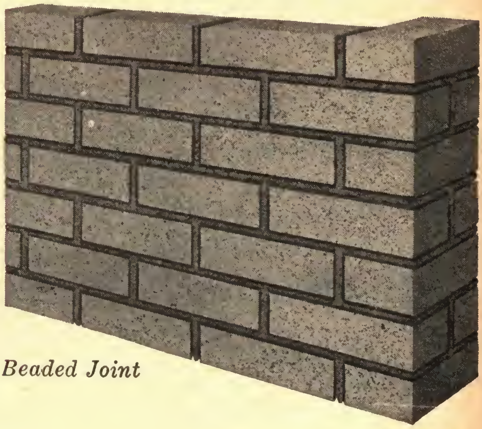
Weathered Joint



Set-Back, or Stripped, Joint



V-Shaped Joint



Beaded Joint

Joints F, G, and H are joints that are normally kept quite small and are formed by the use of a steel jointer which, in order to make the lines true, is drawn along a straight edge. These joints are effective in resisting rain penetration and are recommended for use in areas subjected to heavy rains accompanied by high winds.

Terrace floors and steps, when built of brick, are usually pointed with what is called a "thumb" joint, which is a broad slightly concave joint thoroughly rubbed down with a steel jointing tool. It is good practice to have the exposed face of brick used for terrace floors and steps given a good coat of raw linseed oil immediately before laying, as this practice prevents the mortar from sticking to the face of the brick and permits of clean, clear, finished work.

1208. USE OF COLORED MORTAR

The addition of color to mortar is one of the expedients that is at the command of the designer of artistic brickwork, to produce that nice degree of harmony of the total wall surface so frequently necessary for securing

the essential character of his design. Colored mortar is needed to bring out the life and character of certain tones of brick and is in itself a serious study. The color required to harmonize with certain brick tones can only be found by experiment, and that experiment should always consist of laying a section of sample wall in the colored mortar joint as proposed, large enough to permit a judgment on the finished whole.

There are many fine artistic effects that may be secured by the use of artificially colored mortar which harmonizes with color tones and textures in the brick. Two walls laid of absolutely the same kind of brick will present an altogether different appearance if laid in different colored mortars, an effect that is enhanced if, in addition, there are used different forms of joint. In one wall use a rough-cut flush joint of dark mortar, and in the other a light mortar raked out deep, and the observer could hardly be persuaded that the same brick had been used in both walls. But mortar colors, the reader must be advised, are materials rather difficult to deal with, and the greatest care must be taken in their selection, not only to secure just the shade wanted but to avoid using those that are chemically affected by the lime or cement of the mortar. (See Chapter 5.) An otherwise beautiful wall may be almost ruined by a false tone of color (artificial or natural) in the joint, while, on the other hand, its beauty may be greatly refined and enhanced by the employment of a harmonious color in the mortar.

There are two methods by which colored mortar may be used. The first is its use as the actual working mortar in which the wall is laid. The second is its use in tuck-pointing the wall at the completion of the job. In rough-textured joints the first method is practically necessary. Where a steel jointer may be used, tuck-pointing becomes much the best method of producing the desired result. Fortunately for the designer, it is seldom necessary to produce vivid or strong color in a rough-textured joint.

The ideal practice would be first to complete the entire wall with an inch-deep raked joint, and then, after cleaning down the work, to tuck-point it in fair weather from one batch of the properly colored mortar, at one time, and in one operation. Some colors more than others, especially blacks, seem to require this care, for the daily stoppages of the work and other delays show in the bleaching of the last few joints on the top of the unfinished wall, caused by the action of the sun and the elements. But as, in view of the added expense, this is rarely done, the next best expedient is to cover the last few courses at the end of each day's work, and to secure an experienced and conscientious mixer who has the ability and inclination to use exact proportions in reproducing from day to day the uniform batches of colored mortar necessary to complete the work.

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